DOCUMENT RESUME

ED 246 218 CE 039 203

TITLE	Electronic Principles III, 7-7. Military Curriculum Materials for Vocational and Technical Education.
INSTITUTION	Air Force Training Command, Keesler AFB, Miss.; Ohio State Univ., Columbus. National Center for Research in Vocational Education.
SPONS AGENCY	Department of Education, Washington, DC.
PUB DATE	75
NOTE	353p.; Portions of Plan of Instruction may be marginally legible due to poor print quality. For related documents, see CE 039 201-210.
PUB TYPE	Guides - Classroom Use - Materials (For Learner) (051) -- Guides - Classroom Use - Guides (For Teachers) (052)
EDRS PRICE	MF01/PC15 Plus Postage.
DESCRIPTORS	Behavioral Objectives; Course Content; Course Descriptions; *Electric Circuits; *Electronics; Individualized Instruction; Learning Activities; Learning Modules; Pacing; Postsecondary Education; Programed Instructional Materials; Secondary Education; *Technical Education
IDENTIFIERS	Military Curriculum Project; *Troubleshooting

ABSTRACT

This third of 10 blocks of student and teacher materials for a secondary/postsecondary level course in electronics principles comprises one of a number of military-developed curriculum packages selected for adaptation to vocational instruction and curriculum development in a civilian setting. Prerequisites are the previous blocks. This block on RCL circuits contains nine modules covering 93 hours of instruction on oscilloscope (13 hours), series RCL circuits (19), parallel RCL circuits (8), troubleshooting series and parallel RCL circuits (7 hours), series resonance (11), parallel resonance (12), time constraints (12), filters (6), and coupling (5). Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials include a student text; nine guidance packages containing objectives, assignments, and review exercises for each module; and two programmed texts. A digest of the modules in the block is provided for students who need only to review the material. Designed for self- or group-paced instruction, the material can be adapted for individualized instruction. Additional print and audiovisual materials are recommended but not provided. (YLB)

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MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL
Program Information Office
The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4815 within the continental U.S. (except Ohio)

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Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

- Agriculture
- Aviation
- Building & Construction Trades
- Clerical Occupations
- Communications
- Drafting
- Electronics
- Engine Mechanics
- Food Service
- Health
- Heating & Air Conditioning
- Machine Shop
- Management & Supervision
- Meteorology & Navigation
- Photography
- Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
Rebecca S. Douglass
Director
100 North First Street
Springfield, IL 62777
217/782-0759

MIDWEST
Robert Patton
Director
1515 West Sixth Ave.
Stillwater, OK 74704
405/377-2000

NORTHEAST
Joseph F. Kelly, Ph.D.
Director
225 West State Street
Trenton, NJ 08625
609/292-6562

NORTHWEST
William Daniels
Director
Building 17
Airdustrial Park
Olympia, WA 98504
206/753-0879

SOUTHEAST
James F. Shill, Ph.D.
Director
Mississippi State University
Drawer DX
Mississippi State, MS 39762
601/325-2510

WESTERN
Lawrence F. H. Zane, Ph.D.
Director
1776 University Ave.
Honolulu, HI 96822
808/948-7834

ELECTRONIC PRINCIPLES III

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Developed by:

United States Air Force

Development and Review Dates:

July 1974 through November 1975

D.O.T. No.:
003.081

Occupational Area:
Electronics

Target Audiences:
Grades 11-adult

Print Pages:
353

Cost:
$7.25

Availability:
Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

Contents:	Type of Materials:						Instructional Design:				Type of Instruction:	
	Lesson Plans:	Programmed Text:	Student Workbook: No. of pages	Handouts:	Text Materials:	Audio-Visuals:	Performance Objectives:	Tests:	Review Exercises:	Additional Materials Required:	Group Instruction:	Individualized:
Block III – *RCL Circuits*												
Module 20 – **Oscilloscope**	●		19		●	★	●	★	●	★	●	●
Module 21 – **Series RCL Circuits**	●	●	22		●	★	●	★	●	★	●	●
Module 22 – **Parallel RCL Circuits**	●		22		●	★	●	★	●		●	●
Module 23 – **Troubleshooting Series and Parallel RCL Circuits**	●	●	8		●		●	★	●	★	●	●
Module 24 – **Series Resonance**	●		12		●	★	●	★	●	★	●	●
Module 25 – **Parallel Resonance**	●		11		●	★	●	★	●	★	●	●
Module 26 – **Time Constraints**	●		18		●	★	●	★	●	★	●	●
Module 27 – **Filters**	●		10		●	★	●	★	●		●	●
Module 28 – **Coupling**	●		8		●	★	●	★	●		●	●

★ **Materials are recommended but not provided.**

Expires July 1, 1978

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Course Description:

This block is the third of ten blocks providing training in electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles and troubleshooting basic circuits. Prerequisites to this block are Block I—*DC Circuits* and Block II—*AC Circuits*. Block III—*RCL Circuits* contains nine modules covering 93 hours of instruction on the oscilloscope, series and parallel circuits, troubleshooting, resonance, filters, and time constants. The modules topics and respective hours follow:

Module 20	–	**Oscilloscope** (13 hours)
Module 21	–	**Series RCL Circuits** (19 hours)
Module 22	–	**Parallel RCL Circuits** (8 hours)
Module 23	–	**Troubleshooting Series and Parallel RCL Circuits** (7 hours)
Module 24	–	**Series Resonance** (11 hours)
Module 25	–	**Parallel Resonance** (12 hours)
Module 26	–	**Time Constraints** (12 hours)
Module 27	–	**Filters** (6 hours)
Module 28	–	**Coupling** (5 hours)

This block contains both teacher and student materials. Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials consists of a student text used for all the modules; nine guidance packages containing objectives, assignments, and review exercises for each module; and two programmed texts on series reactive circuits and troubleshooting series and parallel RCL circuits. A digest of modules 20 through 28 for students who have background in these topics and only need to review the major points of instruction is also provided.

This material is designed for self- or group-paced instruction to be used with the remaining nine blocks. Most of the materials can be adapted for individualized instruction. Some additional military manuals and commercially produced texts are recomended as references, but are not provided. Audiovisuals suggested for use with the entire course consist of 143 videotapes which are not provided.

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PLAN OF INSTRUCTION
(Technical Training)

ELECTRONIC PRINCIPLES
(Modular Self-Paced)

KEESLER TECHNICAL TRAINING CENTER

6 November 1975 - Effective 6 January 1976 with Class 760106

Volume 3

7-7

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DEPARTMENT OF THE AIR FORCE
USAF Sch of Applied Aerosp Sci (ATC)
Keesler Air Force Base, Mississippi 39534

PLAN OF INSTRUCTION 3AQR30020-1
6 November 1975

FOREWORD

1. PURPOSE: This publication is the plan of instruction (POI) when the pages shown on page A are bound into a single document. The POI prescribes the qualitative requirements for Course Number 3AQR30020-1, Electronic Principles (Modular Self-Paced) in terms of criterion objectives and teaching steps presented by modules of instruction and shows duration, correlation with the training standard, and support materials and guidance. When separated into modules of instruction, it becomes Part I of the lesson plan. This POI was developed under the provisions of ATCR 50-5, Instructional System Development, and ATCR 52-7, Plans of Instruction and Lesson Plans.

2. COURSE DESIGN/DESCRIPTION. The instructional design for this course is Modular Scheduling and Self-Pacing; however, this POI can also be used for Group Pacing. The course trains both non-prior service airmen personnel and selected re-enlistees for subsequent entry into the equipment oriented phase of basic courses supporting 303XX, 304XX, 307XX, 309XX and 328XX AFSCs. Technical Training includes electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles, and troubleshooting of basic circuits. Students assigned to any one course will receive training only in those modules needed to complement the training program in the equipment phase. Related training includes traffic safety, commander's calls/briefings and end of course appointments.

3. TRAINING EQUIPMENT. The number shown in parentheses after equipment listed as Training Equipment under SUPPORT MATERIALS AND GUIDANCE is the planned number of students assigned to each equipment unit.

4. REFERENCES. This plan of instruction is based on Course Training Standard KE52-3AQR30020-1, 27 June 1975 and Course Chart 3AQR30020-1, 27 June 1975.

FOR THE COMMANDER

W. H. HORNE, Colonel, USAF
Commander
Tech Tng Gp Prov, 3395th

OPR: Tech Tng Gp Prov, 3395th
DISTRIBUTION: Listed on Page A

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
III	RCL Circuits

1 COURSE CONTENT	2 DURATION (Hours)
1. Oscilloscope Uses (Module 20)	13 (10/3)
a. Given an oscilloscope, trainer, and formulas, measure the time and calculate the frequency of an AC voltage within ± 10 percent accuracy. CTS: 2a Meas. [illegible]	(4)
(1) Familiarization with scope controls	
(2) Calculate frequency of voltage waveshapes	
b. Given a dual trace oscilloscope and trainer, determine within ± 10 percent accuracy the phase relationship by comparing two signals of the same frequency. CTS: 2a Meas: PC	(3)
c. Given an oscilloscope and trainer, measure the amplitude of DC and AC voltages ± 10 percent accuracy. CTS: 2a Meas: PC	(3)

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[illegible]	5 November 1975	43

ATC FORM 133 APR 73 ATC Keesler [illegible] REPLACES ATC FORMS 133, MAR 73, AND 770, AUG 72 WHICH WILL BE USED.

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PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-20, Oscilloscope Uses
KEP-ST-III
KEP-107
KEP-108
KEP-110

Audio Visual Aids
TVK-30-212A, Use of Oscilloscope (controls & voltage measurement)
TVK-30-212B, Use of Oscilloscope (frequency & phase measurement)

Training Equipment
Oscilloscope AN/USM-398(1)
Sine-Square Wave Generator 4864 (1)
DC Power Supply 4649 (1)
Multimeter AN/PSM-6 (1)
AC Inductor and Capacitor Trainer 5967 (1)

Training Methods
Discussion (7 hrs) and/or Programmed Self Instruction
Performance (3 hrs)
CTT Assignments (3 hrs)

Multiple Instructor Requirements
Equipment (2)

Instructional Guidance
Issue KEP-GP-20, Oscilloscope Uses, and have students perform lab exercises. Administer progress check to each student and record results. Have students answer applicable questions in KEP-GP-20 during CTT time.

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR:

COURSE TITLE: Electronic Principles

BLOCK NUMBER: III

BLOCK TITLE: RCL Circuits

1 COURSE CONTENT	2 DURATION (Hours)
2. Series RCL Circuits (Module 21)	19 (14/5)
a. Given an AC series RCL circuit with applied voltage, total current, resistance values and formulas, solve for true power and apparent power. CTS: 4e Meas: W	(6)
(1) Solve for true power and apparent power in an	
(a) RC circuit	
(b) RL circuit	
(c) RCL circuit	
b. Given a series RCL circuit with component values, applied voltages, and frequency indicated, calculate the values of and plot the vectors for total impedance, total current, all voltages, and approximate phase angle. CTS: 4f Meas: W	(6)
(1) Given a series RC circuit with component values, applied voltage, and frequency, calculate the values of and plot the vectors for	
(a) total impedance	
(b) total current	
(c) All voltages	
(d) approximate phase angle	
(2) Given an RC circuit, vary parameters individually and determine the effect on current and voltage.	

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PLAN OF INSTRUCTION NO. 3AQR30020-1

DATE: 6 November 1975

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(3) Given a series RL circuit with component values, applied voltage, and frequency, calculate the values of and plot the vectors for

(a) total impedance.

(b) total current.

(c) all voltages.

(d) approximate phase angle.

(4) Given an RL circuit, vary parameters individually and determine the effect on current voltage.

(5) Given a series RCL circuit with component values, applied voltage, and frequency, calculate the values of and plot the vectors for

(a) total impedance.

(b) total current

(c) all voltages.

(d) approximate phase angle.

(6) Given an RCL circuit, vary parameters individually and determine the effect on current and voltage.

c. Using an oscilloscope and trainer, determine relative amplitude and phase relationship of E_a, E_R, E_L, and E_C in a series RCL circuit. CTS: 4f Meas: PC (2)

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-21, Series RCL Circuits
KEP-ST-111
KEP-107
KEP-110
KEP-PT-21, Series RCL Circuits

Audio Visual Aids
TVK 30-257, Series RC Circuits
TVK-30-258, Series RL Circuits

Training Equipment
Oscilloscope AN/USM-398(1)
AC Inductor and Capacitor Trainer 5967 (1)
Sine-Square Wave Generator 4864 (1)
Isolation Transformer 5124 (1)

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

Training Methods
Discussion (12 hrs) and/or Programmed Self Instruction
Performance (2 hrs)
CTT Assignments (5 hrs)

Multiple Instructor Requirements
Equipment (2)

Instructional Guidance

Continue to check student proficiency in use of powers of ten in problem solving. Issue KEP-GP-21, Series RCL circuits, and have students perform laboratory exercise. Monitor students for proper safety precautions and use of equipment. Administer progress check and record results of each individual. Assign specific objectives to be completed in KEP-GP-21 during CTT time.

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
III	RCL Circuits

1 COURSE CONTENT	2 DURATION (Hours)
3. Parallel RCL Circuits (Module 22)	8 (6/2)

a. Given an AC parallel RCL circuit with applied voltage, total current, resistance values and formulas, solve for true power and apparent power. CTS: 4e Meas: W

(1) Solve for true power and apparent power in

(a) parallel RC circuits

(b) parallel RL circuits

(c) parallel RCL circuits

b. Given parallel RCL circuit and vector diagrams, select the vector diagram, representing the relative amplitude and phase relationships of I_t, I_R, I_C, and I_L. CTS: 4f Meas: W

(1) List criteria for determining reference vector.

(2) State relationships of I_t, I_R, I_C and I_L.

c. Given a parallel RCL circuit diagram with component values, frequency, amplitude of applied voltage, and formulas, solve for branch currents, approximate phase angle, total current, and total impedance. CTS: 4f Meas: W

(1) Solve for branch currents, approximate phase angle, total current and total impedance in:

(a) parallel RC circuits

(b) parallel RL circuits

(c) parallel RCL circuits

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COURSE CONTENT

d. Given a parallel RCL circuit diagram with component values, branch currents and formulas, solve for applied voltage. CTS: 4f Meas: W

(1) Solve for applied voltage in

(a) parallel RC circuits

(b) parallel RL circuits

(c) parallel RCL circuits

e. Given a parallel RCL circuit diagram with component values and formulas, solve for total impedance by assuming an applied voltage. CTS: 4f Meas: W

(1) Assume an applied voltage and solve for total impedance in

(a) parallel RC circuits

(b) parallel RL circuits

(c) parallel RCL circuits

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-22, Parallel RCL Circuits
KEP-ST-III
KEP-107
KEP-110

Audio Visual Aids
TVK-30-261, Parallel RC Circuits
TVK-30-263, Parallel RCL Circuits
TVK-30-262, Parallel RL Circuits

Training Methods
Discussion (6 hrs) and/or Programmed Self Instruction
CTT Assignments (2 hrs)

Instructional Guidance
Issue KEP-GP-22 and assign specific objectives to be accomplished during CTT time.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER III	BLOCK TITLE RCL Circuits

1 COURSE CONTENT	2 DURATION (Hours)
4. Troubleshooting Series and Parallel RCL Circuits (Module 23)	7 (5/2)
a. From a group of statements, select the procedure for checking capacitors for opens and shorts. CTS: 4f Meas: W	
(1) Describe procedures for making an ohmmeters check. List indications that a capacitor is good, open or shorted.	
(2) Part substitution.	
b. From a group of statements, select the procedure for checking inductors for opens and shorts. CTS: 4f Meas: W	
(1) Describe procedures for making an ohmmeter check and list indications that an inductor is good, open or shorted.	
c. Using the multimeter, a schematic diagram, and a trainer having an inoperative series RCL circuit, locate the open or shorted component. CTS: 4f Meas: PC	
5. Measurement and Critique (Part 1 of 3 Parts)	1
a. Measurement test	
b. Test critique	

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SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials

KEP-GP-23, Troubleshooting Series and Parallel RCL Circuits
KEP-ST-III
KEP-107
KEP-108
KEP-110
KEP-PT-23, Troubleshooting Series and Parallel RCL Circuits

Training Equipment

Inductor and Capacitor Trainer 5967 (1)
Sine-Square Wave Generator 4864 (1)
Multimeter AN/PSM-6 (1)

Training Methods

Discussion (4 hrs) and/or Programmed Self Instruction
Performance (1 hr)
CTT Assignments (2 hrs)

Multiple Instructor Requirements

Equipment (2)

Instructional Guidance

Issue KEP-GP-23 and have student perform laboratory exercise. Administer progress check and record results for each student. Assign specific objectives to be accomplished in KEP-GP-23 using CTT time. Inform students that a measurement test must be taken covering modules 20 through 23.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER III	BLOCK TITLE RCL Circuits

1 COURSE CONTENT	2 DURATION (Hours)
6. Series Resonance (Module 24)	11 (8/3)
a. Given the response curve of series RCL circuit, compare the magnitude of current flow at resonance and off resonance. CTS: 4g(4) Meas: W	(2)
(1) With given applied frequency and component values of a series RCL circuit, determine if the circuit is (a) capacitive (b) inductive (c) resistive	
(2) Calculate the resonant frequency.	
(3) Compare magnitude of current at resonance and off resonance	
b. Given a series RCL circuit, and vector representations of current and voltage, select the representation which which shows current and voltage relationships below resonance, above resonance, and at resonance, CTS: 4g(4) Meas: W	(2)
(1) With known component values of a series RCL circuit, calculate the resonant frequency and draw vector representations of current and voltage.	
(2) Assume values that will cause the circuit to operate below resonance. Plot the vectors.	
(3) Assume values that will cause the circuit to operate above resonance. Plot the vectors.	

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PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

(4) Select the features of the vector representations that identify the circuit as operating below resonance, above resonance or at resonance.

(5) Given a graph of a frequency response curve, determine bandpass and bandwidth.

c. Given a series of RCL circuits and formulas, determine the effects on current, impedance, and phase angle by varying individually frequency, resistance, capacitance, or inductance. CTS: 4g(4) Meas: W (2)

(1) With known values of frequency, resistance, capacitance and inductance for a series RCL circuit, solve for current, impedance, and phase angle.

(2) Individually substitute values above and below the given values of frequency, resistance, capacitance and inductance and solve for current, impedance and phase angle.

(3) Compare the effects of varying each parameters.

d. Given component values of a series RCL circuit, calculate the resonant frequency. CTS: 4g(4) Meas: W (1)

e. Using a series RCL circuit connected on a trainer, signal generator, and ammeter, determine the half power points, bandwidth, bandpass, and resonant frequency. CTS: 4g(1), 4g(2), 4g(3) Meas: PC (1)

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-24, Series Resonance
KEO-ST-III
KEP-107
KEP-108
KEP-110

Audio Visual Aids
TVK-30-260, Series RCL Circuits (Resonance)

Training Equipment
AC Inductor and Capacitor Trainer 5967 (1)
Sine-Square Wave Generator 4864(1)
Meter Panel 4568 (1)
Multimeter AN/PSM-6 (1)

Training Methods
Discussion (7 hrs) and/or Programmed Self Instruction
Performance (1 hr). CTT Assignments (3 hrs)

Multiple Instructor Requirements
Equipment (2)

Instructional Guidance
Issue KEP-GP-24 and have students perform laboratory exercise. Administer progress check and record results for each student. Assign specific objective for students to complete during CTT time.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER III	BLOCK TITLE RCL Circuits

1 COURSE CONTENT	2 DURATION (Hours)
7. Parallel Resonance (Module 25)	12 (9/3)
a. Given the response curves of parallel RCL circuits, compare the magnitude of current flow at resonance and off resonance. CTS: 4g(4) Meas: W	(3)
(1) With given applied frequency and component values of a parallel RCL circuit, determine if the circuit is capacitive, inductive or resistive.	
(2) Calculate the resonant frequency	
(3) Compare magnitude of current at resonance and off resonance	
b. Given a parallel RCL circuit and formulas, determine the effects on current, impedance, and phase angle by individually varying frequency, resistance, capacitance and inductance. CTS: 4g(4) Meas: W	(4)
(1) With given component values of a parallel RCL circuit, calculate the resonant frequency and draw vector representations of current and voltage.	
(2) Assume values that will cause the circuit to operate below resonance. Plot the vectors	
(3) Assume values that will cause the circuit to operate above resonance. Plot the vectors	
(4) Select the features of the vector representations that identify the circuit as operating at resonance, above resonance or below resonance.	
(5) Given a graph of a frequency response curve, determine the bandpass and bandwidth	

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SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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ATC FORM APR 75 133 ATC Keesler 6-1021 REPLACES ATC FORMS [illegible], MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

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18

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

c. Given component values of a parallel RCL circuit calculate the resonant frequency. CTS: 4g(4) Meas: W (1)

d. Using a parallel RCL circuit connected on a trainer, signal generator, and multimeter, determine the bandwidth, bandpass, half power points, and resonant frequency.
CTS: 4g(1), 4g(2), 4g(3) Meas: PC (1)

8. Measurement and Critique (Part 2 of 3 Parts) 1

a. Measurement test

b. Test critique

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-25, Parallel Resonance
KEP-ST-III
KEP-107
KEO-108
KEP-110

Audio Visual Aids
TVK 30-264, Parallel RCL Circuits (Resonance)

Training Equipment
AC Inductor and Capacitor Trainer 5967 (1)
Sine-Square Wave Generator 4864 (1)
Multimeter AN/PSM-6 (1)

Training Methods
Discussion (8 hrs) and/or Programmed Self Instruction
Performance (1 hr). CTT Assignments (3 hrs)

Multiple Instructor Requirement
Equipment (2)

Instructional Guidance
Issue KEP-GP-25 and have students perform laboratory exercise. Administer progress check and record results for each student. Assign specific objectives to be completed during CTT time. Inform students that a measurement test must be taken covering modules 24 and 25.

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
III	RCL Circuits

1 COURSE CONTENT	2 DURATION (Hours)
9. Time Constants (Module 26)	12 (9/3)
a. Given a DC series RC circuit, specified time component values, and a Universal Time Constant Chart, determine the percent of charge on a capacitor; the percent of discharge of a capacitor. CTS: 4i Meas: W	(2)
(1) Relate the following terms to time:	
(a) Transient	
(b) Transient response	
(c) Transient voltage	
(d) Transient current	
(e) Transient interval	
(2) Effects of component values on transient response.	
(3) Define time constant in terms of RC and RL.	
(4) Explain Universal Time Constant Chart in terms of RC and RL circuits.	
b. Given a DC series RL circuit, specified time, component values, and a Universal Time Constant Chart, determine the percent of current build-up, the percent of current decay. CTS: 4i Meas: W	(2)

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SIGNATURE	DATE	SIGNATURE	DATE

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3AQR30020-I	6 November 1975	59

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PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

(1) RC circuit characteristics.

(a) Identify curve on Universal Time Constant Chart that shows percent of charge and discharge of a capacitor in a DC series RC circuit.

(b) Use a DC series RC circuit and Universal Time Constant Chart to determine

1. E_C and E_R when E_a, R, C, and time are known.
2. number of time constants when E_a, E_c, R, and C are known.
3. R when E_a, C, E_C, and t are known.
4. I when E_a, t, C and R are known.
5. C when E_R, t, E_C, and R are known.
6. E_a when E_R, t, R, and C are known.

c. Given series RC and RL circuits with component values and formulas, compute the time constant for each. CTS: 4i Meas: W (2)

d. Given waveshapes of long, medium and short time constants of RC and RL circuits, identify E_C, E_R, and E_L with the correct waveform. CTS: 4i Meas: W (2)

(1) Relate long, medium, and short TC to integrated and differentiated waveforms.

(2) Identify voltage waveforms developed across resistor and capacitor in RC long, medium, and short TC networks.

(3) Identify voltage waveforms developed across resistor and coil in RL long, medium, and short TC networks.

e. Given a trainer containing series RC or RL networks, oscilloscope, specified square wave frequency and voltage, identify the output wave as either differentiated or integrated. CTS: 4i Meas: PC (1)

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
III	RCL Circuits

1 COURSE CONTENT	2 DURATION (Hours)
9. Time Constants (Module 26)	12 (9/3)
a. Given a DC series RC circuit, specified time component values, and a Universal Time Constant Chart, determine the percent of charge on a capacitor; the percent of discharge of a capacitor. CTS: 4i Meas: W	(2)
(1) Relate the following terms to time: (a) Transient (b) Transient response (c) Transient voltage (d) Transient current (e) Transient interval	
(2) Effects of component values on transient response.	
(3) Define time constant in terms of RC and RL.	
(4) Explain Universal Time Constant Chart in terms of RC and RL circuits.	
b. Given a DC series RL circuit, specified time, component values, and a Universal Time Constant Chart, determine the percent of current build-up, the percent of current decay. CTS: 4i Meas: W	(2)

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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(1) RC circuit characteristics.

(a) Identify curve on Universal Time Constant Chart that shows percent of charge and discharge of a capacitor in a DC series RC circuit.

(b) Use a DC series RC circuit and Universal Time Constant Chart to determine

1 E_C and E_R when E_a, R, C, and time are known.

2 number of time constants when E_a, E_c, R, and C are known.

3 R when E_a, C, E_C, and t are known.

4 I when E_a, t, C and R are known.

5 C when E_R, t, E_C, and R are known.

6 E_a when E_R, t, R, and C are known.

c. Given series RC and RL circuits with component values and formulas, compute the time constant for each. CTS: 4i Meas: W (2)

d. Given waveshapes of long, medium and short time constants of RC and RL circuits, identify E_C, E_R, and E_L with the correct waveform. CTS: 4i Meas: W (2)

(1) Relate long, medium, and short TC to integrated and differentiated waveforms.

(2) Identify voltage waveforms developed across resistor and capacitor in RC long, medium, and short TC networks.

(3) Identify voltage waveforms developed across resistor and coil in RL long, medium, and short TC networks.

e. Given a trainer containing series RC or RL networks, oscilloscope, specified square wave frequency and voltage, identify the output wave as either differentiated or integrated. CTS: 4i Meas: PC (1)

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-26, Time Constants
KEP-ST-III
KEP-107
KEP-108
KEP-807, Universal Time Constant Chart

Audio Visual Aids
TVK-30-851, RC Transients
TVK-30-852, RL Transients & Wave Shaping

Training Equipment
AC Inductor and Capacitor Trainer 5967 (1)
Sine-Square Wave Generator 4864 (1)
Oscilloscope AN/USM-398(1)
Isolation Transformer 5124 (1)

Training Methods
Discussion (8 hrs) and/or Programmed Self Instruction
Performance (1 hr)
CTT Assignments (3 hrs)

Multiple Instructor Requirements
Equipment (2)

Instructional Guidance
Issue KEP-GP-26, Time Constants and have students perform laboratory exercise. Administer progress check and record results of each student. Assign specific objectives to be completed during CTT time.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles

BLOCK NUMBER III	BLOCK TITLE RCL Circuits

1 COURSE CONTENT	2 DURATION (Hours)
10. Filters (Module 27)	6 (4/2)

a. From a list of statements concerning filters, select the one that explains the low pass filtering action of a T-section; a Pi-section. CTS: 4j Meas: W

(1) Explain action of a low pass filter utilizing a

(a) L-section filter

(b) T-section filter

(c) Pi-section filter

b. From a list of statements concerning filters, select the one that explains high pass filtering action of a T-section; a Pi-section. CTS: 4j Meas: W

(1) Explain action of a high pass filter utilizing a

(a) L-section filter

(b) T-section filter

(c) Pi-section filter

c. From a list of statements concerning filters, select the one that explains the bandpass filtering action of a parallel resonant circuit; a series-parallel circuit; a series resonant circuit. CTS: 4j Meas: W

(1) Explain action of a bandpass filter utilizing a

(a) parallel resonant circuit

(b) series resonant circuit

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PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

(c) Series-parallel arrangement of a series and parallel resonant circuit

d. From a list of statements concerning filters, select the one that explains the band reject filtering action of a parallel resonant circuit; a series-parallel circuit; a series resonant circuit. CTS: 4j Meas: W

(1) Explain action of a bandpass filter utilizing a

(a) Parallel resonant circuit

(b) series resonant circuit

(c) series-parallel arrangement of a series and parallel resonant circuit

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-27, Filters
KEP-ST-III
KEP-107
KEP-110

Audio Visual Aids
TVK-30-305, Filters A
TVK-30-306, Filters B

Training Methods
Discussion (4 hrs) and/or Programmed Self Instruction
CTT Assignments (2 hrs)

Instructional Guidance
Issue KEP-GP-27 and assign specific objectives to be completed during CTT time.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER III	BLOCK TITLE RCL Circuits

1 COURSE CONTENT	2 DURATION (Hours)
11. Coupling (Module 28)	5 (4/1)

11. Coupling (Module 28)

a. Given circuit diagrams and a list of statements, select the statement(s) that explain(s) the operation of direct coupling; RC coupling; LC coupling; transformer coupling. CTS: 4j Meas: W

(1) For each type of coupling

(a) draw schematic representation

(b) list characteristics

(c) illustrate response curves

b. From a list of statements, select the one(s) that describe(s) the types of coupling that will provide impedance matching; desired frequency response; signal gain. CTS: 4j Meas: W

(1) State requirements for impedance matching

(2) Illustrate results of using each type of coupling as an impedance matching device

(3) Select the proper coupling for a given desired frequency response

(4) Compare signal gain from each type of coupling

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-28, Coupling
KEP-ST-III
KEP-107
KEP-110

Audio Visual Aids
TVK 30-308, Coupling

Training Methods
Discussion (4 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

12. Measurement and Critique (Part 3 of 3 Parts)

    a. Measurement test

    b. Test critique

Instructional Guidance
Issue KEP-GP-28 and make specific assignments to be accomplished during CTT time. Inform students that a measurement test must be taken covering modules 26, 27 and 28.

28

ATC ST 3AQR3X020-X
Prepared by Keesler TTC
KEP ST/DIGEST III

Technical Training

Electronic Principles (Modular Self-Paced)

Block III

DIGEST

1 April 1975

AIR TRAINING COMMAND

7-7

Designed For ATC Course Use

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Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

Student Text 3AQR3X020-X
KEP-ST/DIGEST I-III
1 April 1975

DIGESTS

The digest is designed as a refresher for students with electronics experience and/or education who may not need to study any of the other resources in detail.

After reading a digest, if you feel that you can accomplish the objectives of the module, take the module self-check in the back of the Guidance Package. If you decide not to take the self-check, select another resource and begin study.

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~~Pole pieces are used to concentrate the magnetic lines. The pole pieces and the armature core provide a low reluctance path.~~

~~With a single coil for the armature winding, a complete cycle of AC will be produced for each revolution. See figure 2. As the coil rotates from 0° it cuts the magnetic lines of force inducing an EMF in the coil. This EMF causes current to flow through the conductor, slip rings, brushes, and load. At the 90° position the conductor cuts the most lines per unit of time and thus maximum voltage is induced. At the 180° point the conductors move parallel to the magnetic lines and the output voltage will be zero. At 270° the output is maximum negative. At 360° point, the cycle will start over. Maximum amplitude is directly proportional to the speed of rotation and the strength of the magnetic field.~~

~~Now that the operation of the AC generator is understood, let's make a minor change to produce a DC output.~~

~~Applying the left-hand rule we can see that the direction of current flow in the conductor changes as coil rotates. This reversal takes place at the 0° and 180° positions. By a switching action this reversal of current through the load can be eliminated by replacing the two slip rings with a commutator. For a single loop armature winding a two segment commutator is used. If the armature winding has two loops then a four segment commutator would be used. One end of each loop is connected to a segment. Two brushes are used to make contact with the rotating commutator just as in the AC generator.~~

~~All motors operate on the interaction of magnetic fields. A force is exerted between a stator field and the field of the armature which is free to rotate. The amount and direction of this force will determine motor speed and direction of rotation. Speed is also a function of frequency and the number of pole pairs in the AC motor.~~

MODULE 20

OSCILLOSCOPE USES

There are numerous applications for a general purpose oscilloscope. Four basic applications will be described in this digest. Once you become familiar with the controls and modes of operation, you will find the oscilloscope is a valuable tool in the troubleshooting and repair of electronic equipment.

To obtain maximum utilization of the oscilloscope, you must learn the controls and their functions. The function of the FOCUS, INTENSITY, and POWER AND SCALE ILLUMINATION controls is self-explanatory. The MODE (Red), TRIGGER SELECTOR, STABILITY (Red) and TRIGGERING LEVEL controls are used to LOCK-IN or stabilize the presentation on the CRT. The HORIZ DISPLAY, VARIABLE TIME/DIV (Red) TIME/DIV, and HORIZONTAL POSITION controls select, control, and position the horizontal display with respect to the X axis. In addition, the HORIZ DISPLAY control selects a normal display, 5X MAG display, or an external horizontal input with its associated EXT HORIZ GAIN control. The oscilloscope can be used to accurately measure the time of waveshapes.

This oscilloscope is a dual trace oscilloscope. This means that two signals can be displayed on the CRT simultaneously. To accomplish this function, two separate and identical vertical size and positioning controls are provided: One labeled channel A and the other channel B. In addition, there is a MODE control which allows you to observe either channel A or channel B. Also CHOPPED or ALTERNATE positions are available. In the CHOPPED mode, each channel is displayed alternately for 3.33 microseconds. In the ALTERNATE position channel A is displayed for a full sweep, then channel B for a full sweep. The VARIABLE VOLTS/DIV (Red), VOLTS/DIV, the POSITION (Red) controls vary the vertical size and position of the waveshape. A POLARITY control selects either AC or DC coupling and provides a normal or inverted input. The oscilloscope can accurately measure the voltage amplitude of a waveshape.

The oscilloscope is a very accurate piece of test equipment and is widely used to observe waveforms to insure their correct shape as indicated in technical orders and operating instructions. Many problems or troubles can be identified with the oscilloscope.

The oscilloscope can also compare the phase relationship between two signals. With the dual trace capability, two signals can be compared by measuring the distance between the waves and multiplying by 360° provides the phase difference, expressed in degrees.

Another function of the oscilloscope is to determine the frequency of a waveform through the accurate measurement of time. The oscilloscope allows you to set the time it takes for the beam to travel 1 centimeter across the CRT. Multiplying the time by the number of centimeters in one cycle will give the time of one cycle. The unknown frequency can then be determined by using the formula: Frequency = 1/Time. Of course, in the formula, time is the time for one cycle.

The last function of the oscilloscope is that of measuring voltage. The oscilloscope allows you to set the amount of voltage needed to make the electron beam deflect 1 centimeter in the vertical direction on the CRT. The AMPLITUDE CALIBRATOR provides an amplitude calibrated 1000 cycle square wave to calibrate the vertical channel of the oscilloscope. By multiplying voltage for 1 centimeter of deflection by the number of centimeters between the positive peak and the negative peak will give the peak-to-peak amplitude of the waveform. The effective, average, and peak voltages of a sine wave can be easily calculated using the peak-to-peak value. DC voltages can also be measured. Ground the input to the scope to set up a reference. Now apply the DC voltage and count the number of centimeters of deflection from the reference. Multiply the centimeters of deflection by the setting of the VOLTS/DIV control to determine the amplitude of the DC voltage.

MODULE 21

SERIES RCL CIRCUITS

You have studied the individual effects of resistance, inductance, and capacitance. All oppose current flow. What is also very important is that inductance and capacitance introduce a phase shift between current and voltage. Resistance does not produce a phase shift. In series RCL circuits it is important to understand this phase shift. Vectors show the phase relationships of current, voltage, resistance, and impedance (Z).

The following properties of a basic series circuit apply:

1. Current in any part of a series circuit is the same. There is only one current in a series circuit.

2. The vector sum of the voltage drops around a closed loop equals the applied voltage.

3. The individual voltage drops can be determined by the use of Ohm's Law.

$$E_R = IR$$

$$E_C = IX_C$$

$$E_L = IX_L$$

Due to the current and voltage relationships across a capacitor and inductor, the phase relationship of X_C and X_L are exactly opposite. As a consequence, X_C and X_L each cancel the effect of the other. When X_L and X_C are in series, the net reactance is the difference between the two series reactances. Three possible conditions exist in such a circuit.

1. X_C is greater than X_L. This makes E_C greater than E_L and the circuit acts capacitive.

2. X_L is greater than X_C. This makes E_L greater than E_C and the circuit acts inductive.

3. X_L equals X_C. This condition is called resonance. This makes E_C equal to E_L and the circuit acts resistive.

The first step in the solution of a series RCL circuit problem is to determine the reactance of the inductor and capacitor. Refer to figure 1 for a sample.

$$X_C = \frac{.159}{fC} = 10 \text{ k ohms}$$

$$X_L = 2\pi \ fL = 20 \text{ k ohms}$$

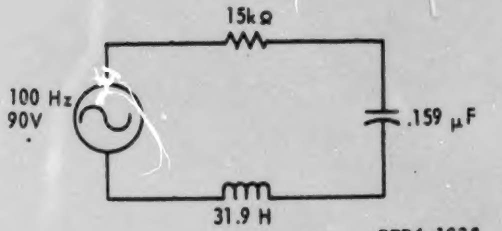

Figure 1

REP4-1028

Next, we solve for total impedance (Z_t) in this circuit by taking the vector sum. Remember that the reactances cancel so subtract the smaller reactance from the larger reactance.

$$Z_t = \sqrt{R^2 + (X_L - X_C)^2} = 18 \text{ k ohms}$$

Knowing the total impedance and the applied voltage, it is easy to determine the total current.

$$I_t = \frac{E_a}{Z_t} = 5 \text{ mA}$$

Individual voltage drops can be determined by using Ohm's Law.

$$E_C = I_t X_C = 50V$$

$$E_L = I_t X_L = 100 \text{ V}$$

$$E_R = I_t R = 75V$$

Vectors show the relationships between resistance, capacitive reactance, and inductive reactance. Figure 2A shows this relationship using resistance as the reference. The angle theta (θ) for Z_t can be determined by using the cosine function.

$$\text{Cos } \theta = \frac{R}{Z_t} = \frac{15 \text{ k ohms}}{18 \text{ k ohms}} = .8333$$

Referring to the trigonometric tables, the angle is 33.6°.

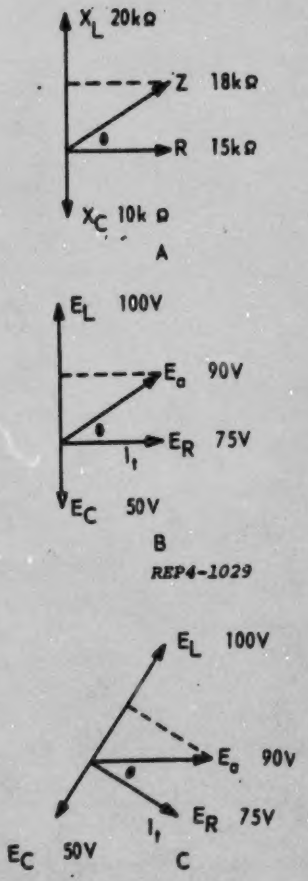

Figure 2

Using current for a reference, we can also plot the current and voltage vectors for this problem. See figure 2B. E_a has the same angle as Z_t, if I_t is used as a reference. E_a is used as the reference in voltage vector diagrams; therefore I_t will be at -33.7°. See figure 2C.

Coils and capacitors store energy during part of the cycle and return it to the circuit during part of the cycle. Therefore, they dissipate no power. Because of this we have to differentiate between true power (P_t) and apparent power (P_a) in a series RCL circuit. True power can only be calculated for the resistor.

$$P_t = I^2R = \frac{E^2}{R} = IE_R = 375 \text{ mW}$$

There is no power dissipated in a pure capacitor or inductor. Although a reactance draws current from the generator, E and I are 90° out of phase. The circuit stores energy in the electromagnetic field of the inductor, and in the electrostatic field of the capacitor. For both cases, the stored energy is returned to the circuit so that no power is dissipated. The product of E_a and I_t then is considered apparent power and is expressed in voltamperes (VA).

$$P_a = E_aI_t = I_t^2Z_t = \frac{E_a^2}{Z_t} = 450 \text{ mVA}$$

Power factor (PF) is a numerical ratio of true power to apparent power.

$$PF = \frac{P_a}{P_t} = \frac{375 \text{ mVA}}{450 \text{ mW}} = .8333$$

Power factor can also be determined by:

$$PF = \frac{E_R}{E_a} = \frac{R}{Z_t} = \cos \theta$$

The power factor is always equal to the cosine of angle theta and can never be greater than one. The closer to one, the more resistive the circuit; and the closer to zero, the more reactive the circuit.

MODULE 22

PARALLEL RCL CIRCUITS

Let us review the properties of a basic parallel RCL circuit.

1. The voltage across each branch of a parallel circuit is the same.

2. Total current is the vector sum of the individual branch currents. Total current will be:

$$I_t = \sqrt{I_R^2 + (I_L - I_C)^2}$$

3. The current in each branch is given by Ohm's Law.

$$I_R = \frac{E_a}{R}$$

$$I_C = \frac{E_a}{X_C}$$

$$I_L = \frac{E_a}{X_L}$$

4. Due to the current and voltage relationships for a capacitor and inductor, the phase relationship of I_C and I_L are exactly opposite. Total reactive current will be the difference between the capacitive current and the inductive current.

A basic parallel RCL circuit is shown in figure 1. The first step in the solution of this parallel RCL problem is to determine X_C and X_L.

$$X_C = \frac{.159}{fC} = 10 \text{ k}\Omega$$

$$X_L = 2\pi fL = 40 \text{ k}\Omega$$

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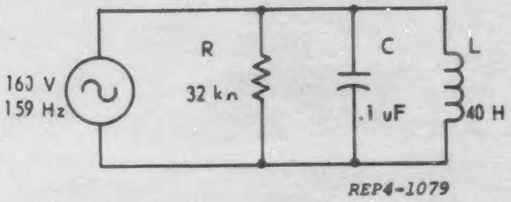

Figure 1

Using Ohm's Law, solve for I_C (16 mA), I_L (4 mA), and I_R (5 mA).

$$I_t = \sqrt{I_R^2 + (I_C - I_L)^2} = 13 \text{ mA}$$

Using total current and the applied voltage, solve for total impedance.

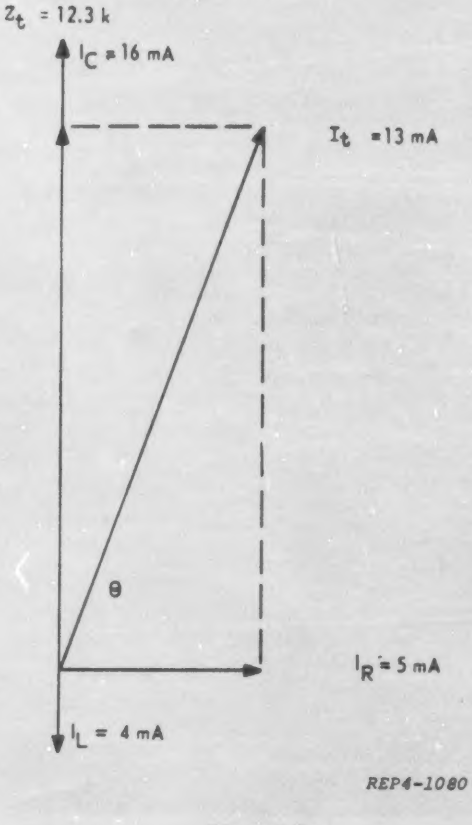

Figure 2

Figure 2 shows the relationship of the current values. Angle θ can be determined by using the cosine function.

$$\text{Cos } \theta = \frac{I_R}{I_t} = \frac{5 \text{ mA}}{13 \text{ mA}} = .3846$$

Referring to the trigonometric tables, find angle θ to be 67.4°.

We say the circuit is acting capacitively if the capacitive current is larger than the inductive current. How the circuit acts is determined by which reactive component has the larger current.

As with series RCL circuits, there is no real power dissipated by the capacitor or the inductor in a parallel RCL circuit. Real or true power (P_t) is the power dissipated by the resistor. The unit of measure of P_t is the watt.

$$P_t = I_R E_R = \frac{E_R^2}{R} = I_R^2 R$$

Apparent power (P_a) is the product of E_a and I_t and is measured in volt amperes (VA).

$$P_a = I_t E_a = \frac{E_a^2}{Z} = I_t^2 Z$$

In this circuit, P_a is 2.08 VA and P_t is 800 mW. Power factor (PF) is the ratio of true power to apparent power.

$$PF = \frac{P_t}{P_a} = \frac{800 \text{ mW}}{2.08 \text{ VA}} = .3846$$

Notice that the PF is the same as the Cos of the phase angle (θ).

When the applied voltage is not given, you can solve for total impedance by using an assumed voltage. Use the assumed voltage and calculate the current through each branch.

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Combine the branch currents to determine total current. Use total current and the assumed voltage to calculate total impedance. Regardless of what voltage is assumed, the impedance will be correct because impedance is the ratio of voltage to current.

MODULE 23

TROUBLESHOOTING SERIES AND PARALLEL RCL CIRCUITS

Troubleshooting RCL circuits is very similar to the procedure used in troubleshooting resistive circuits. However, it is important to know the type of indications reactive components present when troubleshooting for opens and shorts.

Generally a capacitor can be checked with an ohmmeter. A good capacitor will present a momentary deflection towards zero, then the indicator will return to infinity. This procedure is normally used to check large capacitors. With small capacitors it may be difficult to detect this deflection so care must be used. For small capacitors the best check is to replace the capacitor with one that is good. A shorted capacitor will indicate a low or zero resistance when checked with an ohmmeter. An open capacitor will give an infinite reading on the ohmmeter.

In troubleshooting, we will also experience troubles with inductors, and as with capacitors, an ohmmeter can be used. Remember that when using the ohmmeter to check an inductor, you are measuring the DC resistance of the wire. Regardless of the fact the wire is coiled, it is still a conductor and has very little resistance. When the ohmmeter is placed across a coil that is shorted, the meter will indicate 0 ohms. Care must be taken because coils with few turns will show a low resistance reading when they are good. When just a few turns of an inductor short together, it is very difficult to check with an ohmmeter. In this case the best check is to substitute a known good inductor.

MODULE 24

SERIES RESONANCE

In the series RCL circuit, we know that an increase in frequency will produce an increase in X_L and a decrease in X_C. The frequency at which $X_C = X_L$ is called the resonant frequency and is designated by f_r. See figure 1.

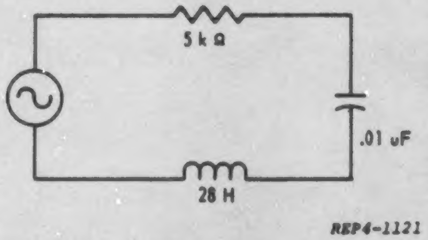


Figure 1

$f_r = 300$ Hz

$E_a = 25$ V

$X_L = 53$ k ohms

$X_C = 53$ k ohms

Z = R (5k ohms)

For every combination of L and C, there will be one frequency where $X_C = X_L$. The formula for determining this frequency is $f_r = .159/\sqrt{LC}$. An important property of a series RCL circuit is that impedance is low at resonance and increases rapidly as frequency is increased or decreased. (Z is equal to R and I_t is maximum.) See figure 2.

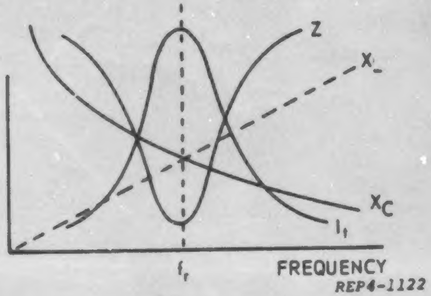


Figure 2

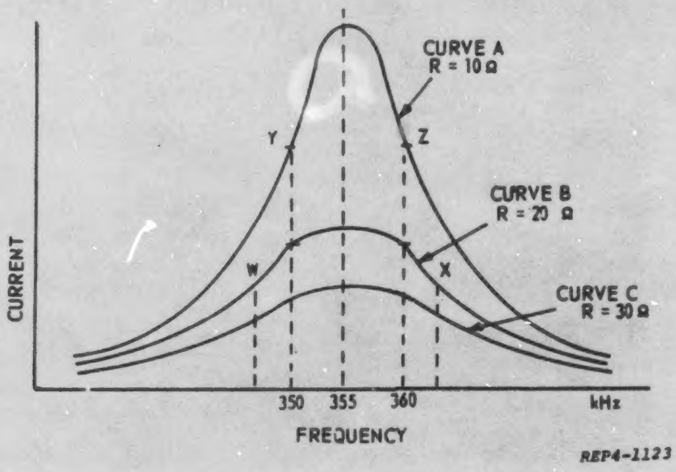
When the applied frequency is less than the resonant frequency, the circuit is capacitive. X_C is greater than X_L. When the applied frequency is greater than the resonant frequency, the circuit is inductive. X_L is greater than X_C. Figure 2 shows the two reactances as well as the total impedance and total current as the frequency is varied from below to above resonance. Notice that circuit impedance is minimum and circuit current is maximum at resonance.

The Q of a series resonant circuit is defined as the ratio of the inductive reactance of the circuit to the resistance of the circuit. The Q of the coil is defined as the ratio of X_L of the coil to the resistance of the coil ($Q = X_L/R$). If a series circuit has only one coil, and the resistance of the circuit is the resistance of the coil, then Q of the circuit and Q of the coil are one and the same. Coils with a Q of 10 or more are said to be high Q coils.

Varying the resistance will not affect resonant frequency but will affect circuit current by affecting Q. Figure 3 shows the effect of changing resistance in a series RCL circuit. Curve A shows the variation in current as the frequency increases from below resonance to above resonance. Note that curve A comes to a much sharper peak than do the other curves. Since in all cases X_L has remained fixed, the Q is greater when the resistance is smaller. The current-frequency resonance curve in a high Q circuit rises to a sharp peak at the resonant frequency and the peak of the curve for lower Q circuit is broader.

In many series RCL circuits, a large number of frequencies may be supplied to the circuit. The current that would meet the least opposition would be that generated at the resonant frequency. We say that the circuit passes the resonant frequency. If it is desired to pass current at a particular frequency, the capacitance or inductance (or both) may be varied so that $X_C = X_L$ at the desired frequency. This is called tuning the circuit. A series RCL circuit is said to be tuned to a given frequency when the capacitance or inductance (or both) have been adjusted so the given frequency becomes the resonant frequency. It can be seen in figure 3 that a high Q circuit is more selective or more sharply tuned since the current at the resonant frequency is much greater than the current slightly off-resonance.

If frequencies (other than the resonant frequency) are passed at a lesser magnitude than the resonant frequency, between what frequencies is a significant amount of current passed? Unless we know what we mean by a significant amount, we cannot answer the



REP4-1123

Figure 3

question. The significant amount is more than .707 times I_{max}. The .707 points on the current-frequency curve (see figure 3) are called the half power points. The half power points on curve A are Y and Z. Drawing a line down from point Y is 350 kHz and from point Z is 360 kHz. The bandwidth is defined as the difference between the upper half power point frequency and the lower half power point frequency. (BW = 360 kHz - 350 kHz = 10 kHz).

The half power points of curve B are W and X. The bandpass in this case is greater than curve A, and the bandwidth is wider. The bandwidth of curve C is wider than either that of A or B. If a series circuit is resonant at a given frequency, increasing R increases the bandpass and decreases selectivity.

When the resonant frequency, f_r and the Q are known, bandwidth may be found by the formula $BW = f_r/Q$.

MODULE 25

PARALLEL RESONANCE

A large number of electronic devices contain parallel resonant circuits. The circuit diagram of figure 1 represents a typical parallel resonant circuit. The resistor may be the resistance of the coil.

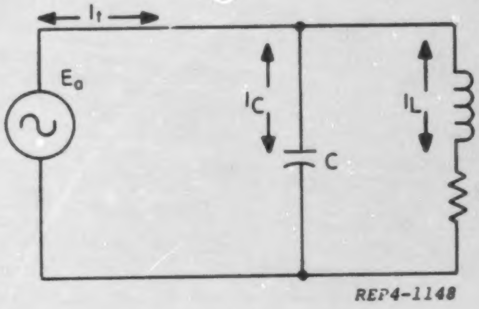


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Figure 1

In parallel RCL circuits, resonance occurs when the frequency causes I_C to equal I_L. This frequency can be determined by the formula $f_r = .159/\sqrt{LC}$.

In figure 1, there are two paths in which current may flow: One through the coil and the other through the capacitor. If the generator is operating below resonance, most of the current will flow in the inductive branch, since at low frequencies X_L is less than X_C. The circuit acts inductively. If the generator is operating above resonance, most of the current will flow in the capacitive branch, since X_C is now lower than X_L. The circuit is acting capacitively. Between these two points there is the resonant frequency, where the inductive current equals the capacitive current. At this point I_C and I_L being equal, but 180° out of phase, cancel each other and the circuit is purely resistive. Total line current is then a result of the resistor and is quite small. At resonance, line current is minimum, circuit impedance is maximum, and the phase angle is zero. See figure 2.

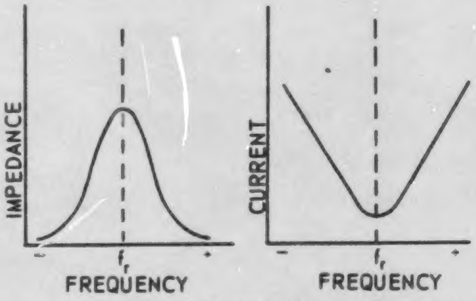
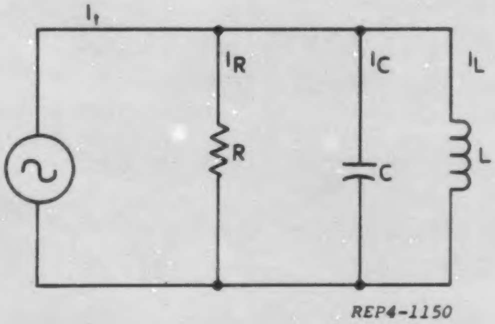


Figure 2 REP4-1149



REP4-1150

Figure 3

Varying either frequency, capacitance, or inductance will cause the line current to increase while circuit impedance decreases. Varying the resistance will not effect resonance, but will effect the Q, thereby causing a change in bandwidth. ($Q = X_L/R$ and bandwidth $= f_r/Q$.)

The three-branch parallel resonant circuit differs slightly from the two-branch circuit when calculating Q. Because of the separate path for current through the parallel resistor, figure 3, the formula for determining the quality of the circuit is $Q = R/X_L$. Therefore,

$$\text{bandwidth} = \frac{f_r \times X_L}{R}$$

MODULE 26

TRANSIENTS

Transients play a very important part in electronic circuits, and for this reason they should be thoroughly understood. Transient voltages and currents come into being as a result of the application, change, or removal of a voltage from an electrical circuit. These can be divided into RC and RL transients.

The RC transient begins with the application of a voltage to a series RC circuit. See figure 1. At first, all the applied voltage appears across the resistor. In time, as the capacitor becomes charged, the voltage drop across the capacitor increases at the expense of the voltage drop across the resistor. The transient comes to an end when the capacitor is charged to the applied voltage. Capacitor voltage opposes the applied voltage and reduces circuit current and resistor voltage to zero.

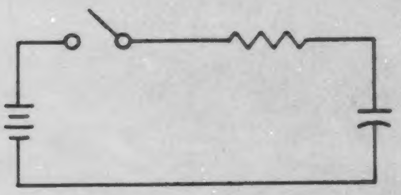


Figure 1

The duration of the transient interval depends on the value of R times C. The product of R in ohms times C in farads is the time constant (TC) in seconds. In one time constant, the capacitor charges to 63% of the applied voltage. For all intents and purposes, the capacitor will be fully charged after five time constants. See figure 2. Using the Universal Time Constant Chart, and the formula $\# TC = \frac{t}{RC}$, the percentage of charge or discharge of a capacitor can be calculated for any given time. With this information, E_C, E_R, and the circuit current can be determined.

A second transient occurs when the applied voltage is removed and the capacitor is allowed to discharge.

The RL transient begins when a voltage is suddenly applied to a series RL circuit.

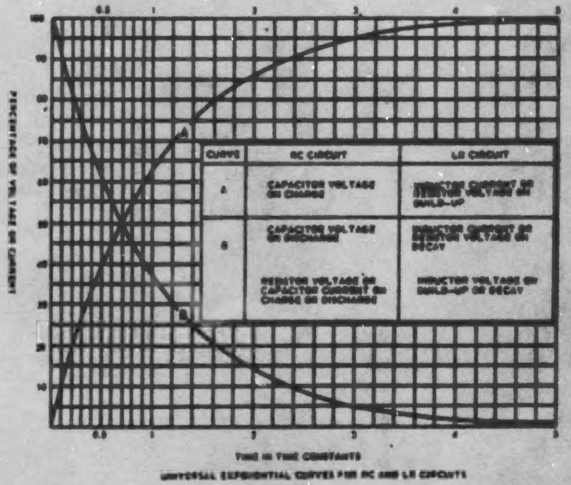
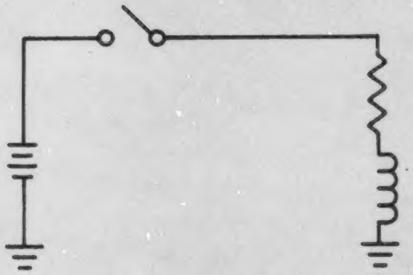


Figure 2. Universal Time Constant Chart



REP4-1194

Figure 3

See figure 3. At first, all of the applied voltage appears across the inductor. As the CEMF of the inductor is overcome, the circuit current and the voltage drop across the resistor increases. As in the case of the RC circuit, the transient state is finished approximately five time constants after the application of voltage. At this time, the voltage across the resistor equals the applied voltage and current is controlled by the resistor. The time constant in seconds is equal to L in henrys divided by R in ohms. Using the Universal Time Constant Chart and the formula $\#TC = \frac{Rt}{L}$, the percentage of current buildup or decay can be calculated for any given time. With this information, coil and resistor voltages as well as circuit current can be determined.

The time required for the current in an inductive circuit to decay to zero, following an initial buildup period, is also 5 time constants. The shape of the voltage waveforms during the current buildup and decay are the same as those encountered during the charge and discharge periods of a capacitor. The difference is that the waveform obtained across the inductor in the one case is obtained across the resistor in the other.

The manner in which an RC circuit responds to the application of a square wave voltage has been analyzed. We know that the output voltage wave may take any form, ranging from that of the input wave to a differentiated version of the input wave. In the latter case, the output is a series of positive and negative going peaked waves. The particular shape of the output waveform depends on (1) the time constant of the RC circuit and (2) the frequency of the input wave. See figure 4.

In general, as the frequency of the input wave becomes higher in relation to the time constant of the RC circuit, the more closely does the resistor waveform resemble the input wave. Conversely, the lower the frequency of the input wave in relation to the RC time constant, the more differentiated (the more peaked) will be the resistor waveform. In the first case, the circuit is said to have a long time constant, while in the latter, the circuit has a short time constant.

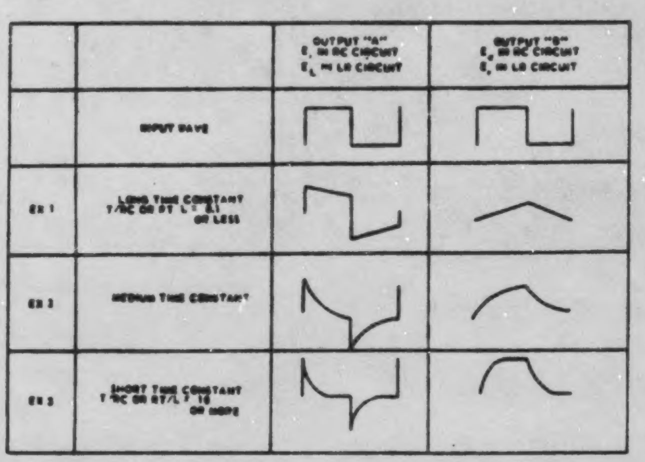

OUTPUT "A" E_R IN RC CIRCUIT E_L IN LR CIRCUIT
OUTPUT "B" E_C IN RC CIRCUIT E_R IN LR CIRCUIT
INPUT WAVE
EX 1
LONG TIME CONSTANT T/RC OR RT/L = 0.1 OR LESS
EX 2
MEDIUM TIME CONSTANT
EX 3
SHORT TIME CONSTANT T/RC OR RT/L = 10 OR MORE

Figure 4

The transient behavior of an RL circuit is analogous to that of an RC circuit. In the RC circuit, the capacitor voltage builds up exponentially with time, while in the RL circuit the current builds up exponentially. The time required for the voltage in the one case, and for current in the other, to build up to 63% of its final value is one time constant. In the latter circuit the time constant is $\frac{L}{R}$. $\frac{L}{R}$ and RC are both measured in seconds. For this reason, the Universal Time Constant Chart is as useful in the solution of RL circuits as it is in the solution of RC circuits.

The terms SHORT and LONG time constants have the same meaning with respect to RL circuits that they do with respect to RC circuits. Accordingly, the waveforms from across the inductor in the RL circuit is equivalent to the waveform obtained across the resistor in the RC circuit. Similarly the voltage waveform obtained across the resistor of the RL circuit is identical to the waveform obtained across the capacitor in the RC circuit.

MODULE 27

FILTERS

A filter circuit consists of a combination of capacitors, inductors, and resistors connected so that they separate unwanted frequencies from desired frequencies. In addition, they can separate an AC signal from a DC signal. These components, and or combination of components, are arranged in basic patterns or sections (identifiable as an "L" section, "T" section, and "Pi" section) to accomplish filtering action. Filter circuits may range from very simple to very complex. Regardless of how simple or complex a filter circuit may be, its basic action depends on the opposition each of its components presents to either alternating current or direct current.

Opposition presented to alternating current by a circuit containing inductance and resistance will increase as frequency increases due to the inductive reactance of the inductor. However, when DC is applied, the inductor presents an opposition for only a short time (CEMF). After the CEMF is overcome, the only opposition to direct current is the resistor.

The opposition to alternating current offered by capacitance decreases with an increase in frequency due to capacitive reactance. However, when DC is applied, the capacitor offers infinite opposition after the capacitor has charged.

A series resonant circuit offers little opposition to frequencies within the resonant band. This circuit will offer more opposition to other frequencies.

A parallel resonant circuit offers a great deal of opposition to frequencies within the resonant band, while offering very little opposition to other frequencies.

Filters are identified by their action. There are four basic types.

Low Pass Filter. This filter will develop, in an output, all frequencies below the cutoff frequency. Frequencies above the cutoff will be attenuated to an unusable level. Proper selection and arrangement of components establishes the cutoff frequency.

High Pass Filter. This filter will develop, in an output, all frequencies above the cutoff frequency. Frequencies below the cutoff will be reduced to an unusable level. Proper selection and arrangement of components establishes the cutoff frequency.

Band Pass Filter. This filter uses resonant circuits. This filter, when properly arranged, will develop the resonant band in an output. All other frequencies will be reduced to an unusable level.

Band Reject Filter. The band reject filter also uses resonant circuits. However, this filter will reduce the resonant band to an unusable level in the output. All other frequencies will be developed and allowed to pass to the next circuit.

In conclusion, a filter circuit consists of a combination of capacitors, inductors, and resistors connected so they will either permit or reject the passage of frequencies or bands of frequencies.

MODULE 28

COUPLING

COUPLING is defined as a means by which signals are transferred from one circuit to another. Two circuits are said to be coupled when they have a common impedance that permits the transfer of electrical energy from one circuit to another. This common impedance, called a coupling element, may be a conductor, an inductor, a capacitor, a transformer, or a combination of two or more of these components. Coupling circuits usually, though not always, perform some filtering action in addition to providing a means of transferring electrical energy from one circuit to another. The choice of name is determined by the function of the circuit that is of greatest importance. Basically, four types of circuits are used for coupling: the directly coupled circuit, the capacitive-resistive coupled circuit, the capacitive-inductive type, and the transformer coupled circuit. Each circuit has its own advantages and disadvantages.

Direct coupling uses a conductor and/or a resistor to connect two circuits together, and provides a direct path for signal currents. See figures 1A and 1B. This type of coupling provides reproduction of the exact signal at the output of the coupling circuit as it appeared in the input. It also allows the DC voltage to be felt at the output of the coupling circuit. In figure 1B, the output will be somewhat lower than the input due to loading effect of the resistor. Direct coupling operates over a wide frequency range.

Resistive-capacitive (RC) coupling is used when the DC must be blocked and only the AC component passed to the output. The capacitor, with its basic action, blocks the DC and allows the AC component to be developed across the resistor. See figure 2.

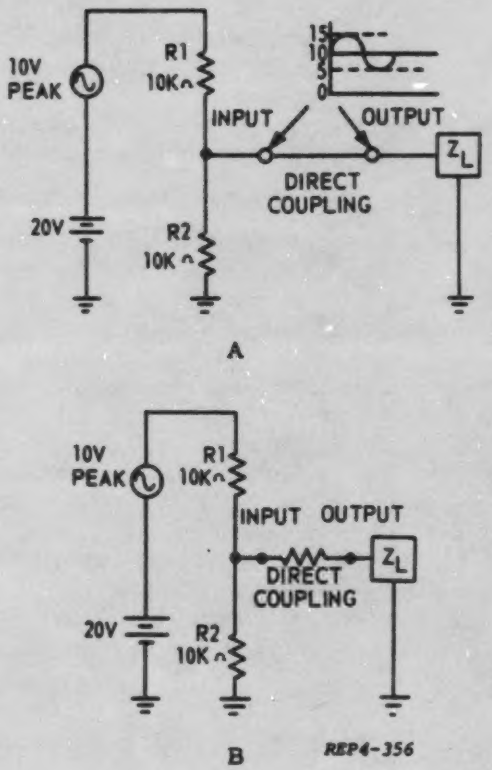

10V
PEAK
R1
10KΩ
15
10
5
0
INPUT
OUTPUT
Z_L
DIRECT
COUPLING
20V
R2
10KΩ
A
10V
PEAK
R1
10KΩ
INPUT
OUTPUT
Z_L
DIRECT
COUPLING
20V
R2
10KΩ
B
REP4-356

Figure 1

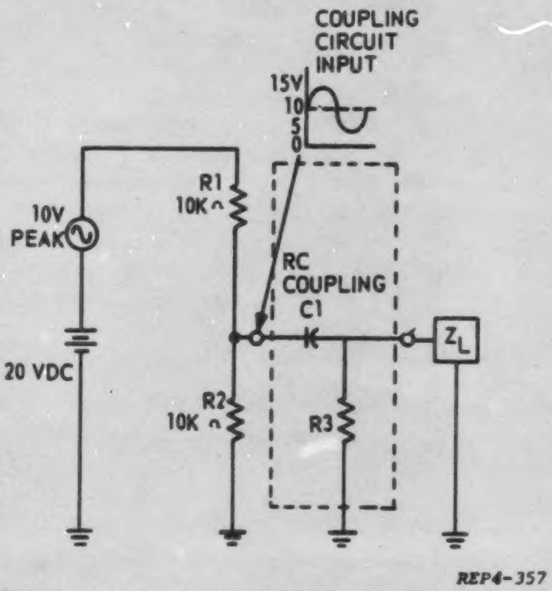

COUPLING
CIRCUIT
INPUT
15V
10
5
0
R1
10KΩ
10V
PEAK
RC
COUPLING
C1
Z_L
20 VDC
R2
10KΩ
R3
REP4-357

Figure 2

Care must be taken in the selection of components. X_C should be 1/10 or smaller than the size of the resistor over the desired band of frequencies. This insures minimum phase shift with maximum transfer of energy in the wanted band of frequencies.

Inductive-capacitive (LC) coupling is similar to RC coupling, but an inductor is used in place of the resistor. Basic operation is the same as RC although the output could be greater than the input at resonance where $X_C = X_L$.

As the name implies, with transformer coupling, a transformer is used to couple two circuits together. A transformer can separate alternating current from direct current as well as step the input voltage up or down. This type of coupling can be used for impedance matching. The transformer is expensive, must be shielded, and has a limited frequency response. It is considered to be inductive coupling.

NOTES

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Volume III

RCL CIRCUITS

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Block 3

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Chapter 1

SERIES RC CIRCUITS

1-1. A series RC circuit is a series circuit that contains both capacitance and resistance. This lesson will add to your knowledge of capacitors and resistors as they apply to a series RC circuit. You will compute the voltage drop across each component; total current, phase angle, and total impedance.

1-2. Impedance is the total opposition offered to the flow of alternating current. This opposition may consist of any combination of resistance, inductive reactance, or capacitive reactance. The symbol for impedance is Z and the unit of measure is the ohm.

1-3. Refer to figure 1-1. This figure shows a series circuit that contains resistance only.

1-4. Voltage and current in a purely resistive circuit are in phase. This can be shown graphically with two sine waves. The two sine waves pass through zero and reach their respective peaks together. This indicates the in-phase relationship. In any circuit, the current through a resistor is in phase with the voltage drop across the resistor.

1-5. Figure 1-2 shows a series circuit containing only capacitance. The sine waves show the capacitor voltage (E_C) lagging capacitor current (I_C). In any circuit, the current through a capacitor leads the capacitor voltage drop by 90 degrees. Current which causes a voltage drop across a capacitor is 90 degrees ahead of the voltage it develops.

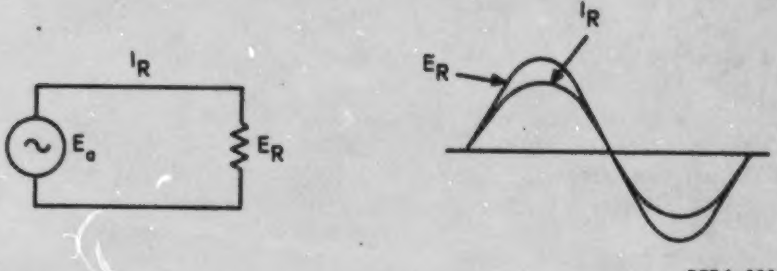

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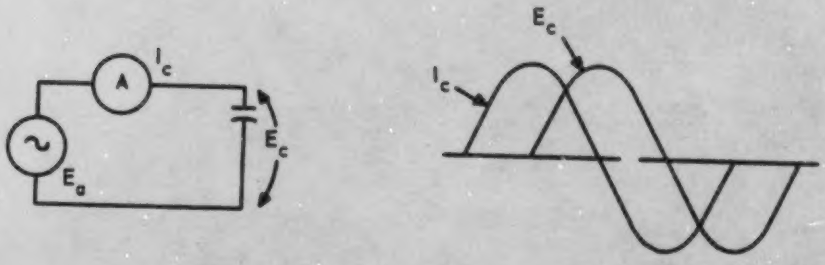
Figure 1-1. AC Circuit Containing Resistance



REP4-340

Figure 1-2. AC Circuit Containing Capacitance

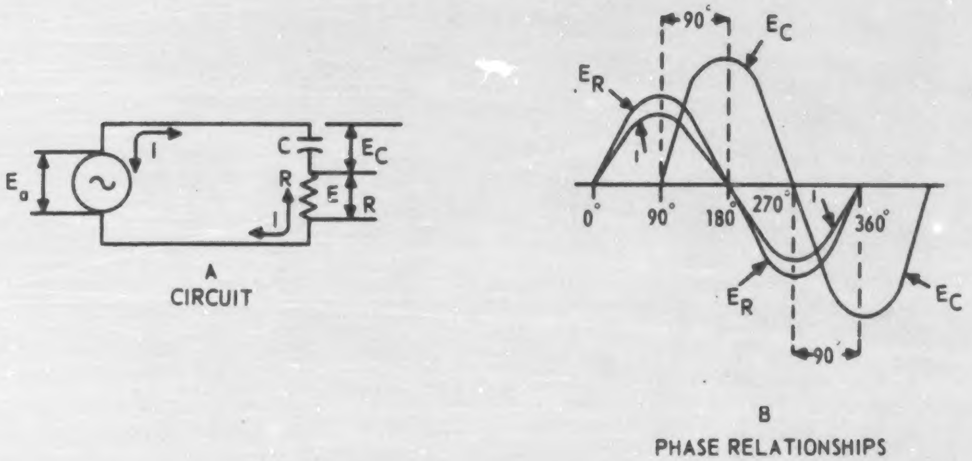
1-6. Figure 1-3 is a series circuit containing both resistance and capacitance. In this circuit, current has one path; the resistor and capacitor have the same current, but the phase relationships of figure 1-1 and 1-2 hold. To show phase relationships in this circuit, the phase diagrams for the resistor and capacitor must be combined using current as the reference. The voltage across the resistor is in phase with the current. The voltage across the capacitor lags the current by 90 degrees as shown in figure 1-3. The instantaneous values of E_R and E_C added together equal the applied voltage (E_a). E_a is not shown in figure 1-3B. If E_R and E_C are equal, E_a lags I by 45 degrees. This method of showing phase and amplitude relationships is accurate, but can become confusing. We can also represent voltage, current, and other forces with a simple graphic symbol called a VECTOR.

1-7. A vector is a line used to represent magnitude and direction. The length of the line denotes magnitude. The arrow head on one end of the line shows direction.

1-8. Earlier in the course a rotating radius vector was used to generate a sine wave. This vector started at a horizontal position to the right, called the "zero reference point." It rotated counterclockwise through 360 degrees. The horizontal vector to the right for the zero reference point and the counterclockwise rotation for positive angles are matters of convention. Rotating the vector clockwise generates a negative angle.

1-9. Voltage and current do not have true direction in terms of three dimensional space; but they do have a phase relationship which can be considered as direction. A vector can thus be used to represent the amplitude and phase relationships of voltage and current.

1-10. The sine waves shown in figure 1-3 can be represented by vectors. Since current is common to all parts of this series circuit, plot the voltages with reference to the current. First, draw the current reference vector, as shown in figure 1-4A. Plot voltage across the resistor (E_R) in phase with I because resistor current and voltage are in-phase, (figure 1-4B). Voltage across the capacitor E_C lags the current



A
CIRCUIT

B
PHASE RELATIONSHIPS

REP4-341

Figure 1-3. Series Circuit Containing Resistance and Capacitance

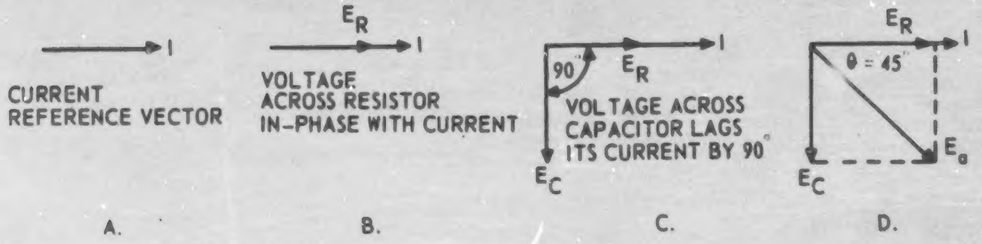


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Figure 1-4

by 90 degrees as shown in figure 1-4C.

1-11. The vector sum of E_R and E_C is the applied voltage, E_a. To add vectors, form a parallelogram (dotted line) and draw the diagonal, as shown in figure 1-4D. The length of the diagonal is the vector sum and represents E_a. The angle measured from E_a to I is the "phase angle" and is designated by the symbol θ (theta). The completed vector diagram now shows total current and resistor voltage leading the applied voltage. Also, capacitor voltage lags the applied voltage. These principles hold true in all capacitive circuits. This information will be used later in this chapter; but first let's review angles, rectangular coordinate system, triangles, and trigonometric relationships. This review gives the mathematical procedures needed to correctly use the vectors for series RC circuits. Later you will use these same mathematical procedures for series RL and RCL circuits.

1-12. An angle is the space between two intersecting straight lines; this is measured in degrees.

1-13. The rotating radius vector forms a plane angle with the horizontal reference line. One quarter of a full revolution of the vector forms a 90 degree angle. One half of a full revolution forms a 180 degree angle, or straight angle. A full revolution forms an angle of 360 degrees and brings the vector back to its original position.

1-14. The horizontal reference line and the extended line of the 90 degree angle form a rectangular coordinate system. On this we plot vectors to show both magnitude and direction. Refer to figure 1-5.

1-15. Remember that there are both positive and negative numbers in our numbering system. They may be shown on one scale where one direction from a reference point is positive and the opposite direction is negative. The rectangular coordinate system consists essentially of two such number scales set at right angles to each other; the zero reference point is called the origin. The horizontal axis is commonly called the "X-axis;" positive to the right and negative to the left. The vertical axis is commonly referred to as the "Y-axis;" positive upward and negative downward. The four sections formed by the X and Y axis are called "quadrants;" they are

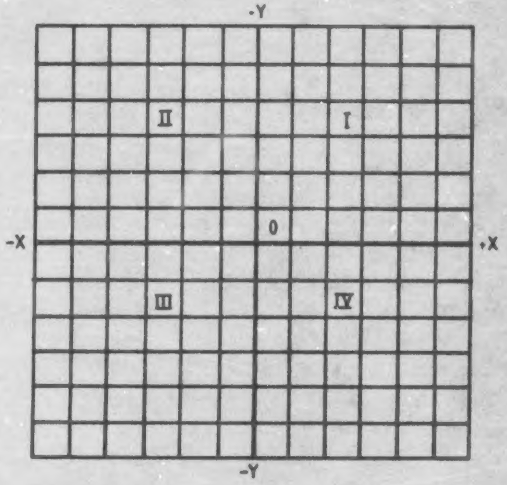

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Figure 1-5. Rectangular Coordinate System

identified counterclockwise as I, II, III, and IV. The dividing lines between adjacent quadrants are the coordinates: +X, +Y, -X, and -Y. Any of the coordinates could be used as a reference. However, we use +X as the reference in our problems. Before using the rectangular coordinate system, let's review triangles.

1-16. In any triangle, the sum of the three angles is 180 degrees. When one angle is a right angle, the triangle is a right triangle. A right angle is equal to 90 degrees. Therefore, the sum of the other two angles in the right triangle must also equal 90 degrees. In figure 1-6, you can find angle B by subtracting angle A from 90 degrees. Regardless of how long the sides are, the sum of all three angles equal 180 degrees.

1-17. If you know two sides of a right triangle you can solve for the third side by arithmetic or by trigonometric functions.

1-18. By arithmetic. Apply the Pythagorean Theorem, which states: In a right triangle the square of the hypotenuse is equal to the sum of the squares of the two sides. The hypotenuse is the longest side of the right triangle and opposite the right angle. This can be expressed by the formula: $c^2 = a^2 + b^2$; where c is the hypotenuse and a and b are the two sides forming the right angle. For example: Refer to figure 1-6A and note that the right triangle has a hypotenuse of 5 units and sides of 3 and 4 units. Now look at figure 1-6B and you will see that we have squared each of the triangle's sides and drawn squares to represent this. Count the unit squares to prove that $c^2 = a^2 + b^2$, in this example $5^2 = 3^2 + 4^2$ or $25 = 9 + 16$. Because we will always want to know the length of one of the sides, we can express the Pythagorean Theorem three different ways depending on the unknown side. In figure 1-7, we will solve for side "b," where the hypotenuse is 13 and side "a" is 5. Find side "b", using the formula

$$b = \sqrt{c^2 - a^2}.$$

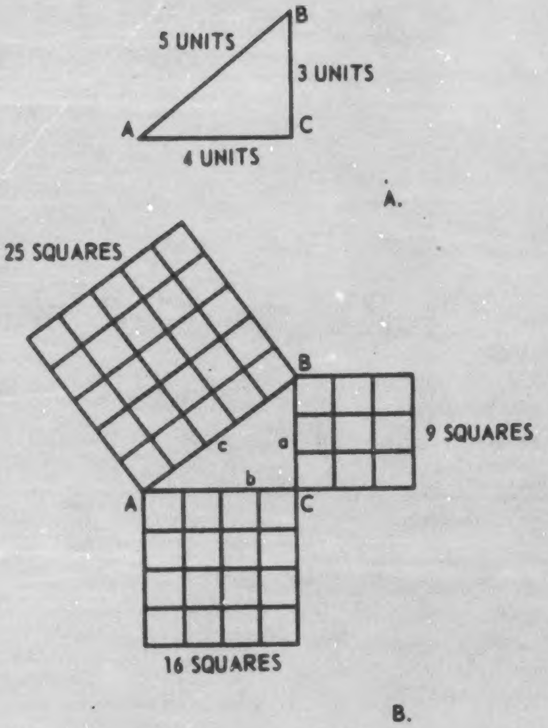

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Figure 1-6

$$b = \sqrt{c^2 - a^2}$$

$$b = \sqrt{13^2 - 5^2} = \sqrt{169 - 25} = \sqrt{144}$$

$$b = 12$$

NOTE: Your Electronics Handbook, KEP110, has a square and square root table for all numbers from 1 through 1000.

$$c = \sqrt{a^2 + b^2}$$

$$b = \sqrt{c^2 - a^2}$$

$$a = \sqrt{c^2 - b^2}$$

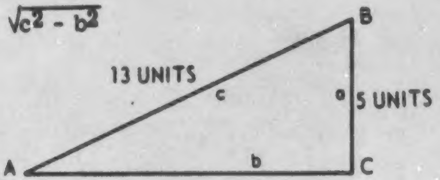
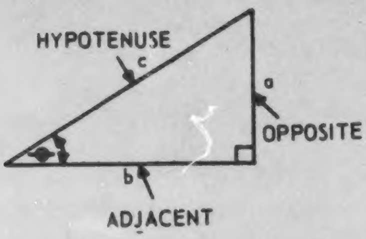


Figure 1-7

REP4-345



$$\text{Sine } \theta = \frac{\text{Opposite}}{\text{Hypotenuse}} = \frac{a}{c}$$

$$\text{Cosine } \theta = \frac{\text{Adjacent}}{\text{Hypotenuse}} = \frac{b}{c}$$

$$\text{Tangent } \theta = \frac{\text{Opposite}}{\text{Adjacent}} = \frac{a}{b}$$

Figure 1-8. Right Triangle with Three Trigonometric Relationships

1-19. By trigonometric functions. The sine, cosine, and tangent functions are defined for angle θ in the right triangle shown in figure 1-8. A trigonometric function is simply the ratio of one side of a triangle to another side of the triangle.

1-20. In figure 1-8, we will identify the angle formed by sides c and b as "θ" (the Greek letter theta). Side c is the "hypotenuse" and side b is the "adjacent" side. The adjacent side is always the side of the right triangle that is NOT the hypotenuse and forms the second side of the angle θ. For example; if we should need to know about the angle formed by sides a and c, then side c would be the hypotenuse and side a would be the adjacent side.

1-21. After becoming thoroughly familiar with the terms "opposite", "adjacent", and "hypotenuse" and their definition, we can use and understand the following:

1. Sine of an angle $(\text{Sin } \theta) = \frac{\text{Opposite side}}{\text{Hypotenuse}}$

2. Cosine of an angle $(\text{Cos } \theta) = \frac{\text{Adjacent side}}{\text{Hypotenuse}}$

3. Tangent of an angle $(\text{Tan } \theta) = \frac{\text{Opposite side}}{\text{Adjacent side}}$

Learn these three functions thoroughly so that you can define and visualize them readily for either of the two angles in a right triangle that are NOT the right angle.

1-22. Using angle θ in figure 1-8, we can define the three principle trigonometric functions as follows:

1. The sine of θ is equal to the ratio of side a to side c. This would be written $\text{Sin } \theta = \frac{a}{c}$.

2. The cosine of θ is equal to the ratio of side b to side c. This would be written $\text{Cos } \theta = \frac{b}{c}$.

3. The tangent of θ is equal to the ratio of side a to side b. This would be written $\text{Tan } \theta = \frac{a}{b}$.

1-23. Trigonometric functions are simply numbers. They give the relative length of one side of a triangle to another side for a given angle in the triangle. For example: If in figure 1-8, side b is 6 inches and side c is 8 inches, then $\text{Cos } \theta = \frac{\text{Adjacent}}{\text{Hypotenuse}} = \frac{b}{c} = \frac{6}{8} = .7500$. This means that side b is .75 as long as side c.

1-24. An angle of the same value will have the same trigonometric value regardless of the length of its two sides. This is true because both sides of an angle (not the right angle) in a right triangle will extend proportionally if the angle's value remains the same. Because of this property, a table of trigonometric values was made that lists the trigonometric values for any angle. We can use this table to find the value of an angle if we know one of its trigonometric values. Also, using the table we can find the trigonometric values if we know the value of the angle. This trigonometric table is located in your Electronics Handbook, KEP 110, figure 31.

1-25. The first and seventh columns of the trigonometric table in your Electronic Handbook are headed DEG and contain the degrees from 0 to 45, reading down. The sixth and twelfth columns contain the angles from 45 degrees to 90 degrees, reading up. For angles from 0 degrees to 45 degrees, use the column headings Sin, Cos, and Tan at the top of the table and read down. For angles of 45 degrees to 90 degrees, use the heading at the bottom of the table and read up. These headings are to the left of the 45 to 90 degree columns.

1-26. For example: Locate the sine value of 32 degrees. Since 32 degrees is between 0 and 45 degrees, look in the first and seventh columns until you locate 32 degrees. Now go to the top of the table and find the column heading "sin". Then come down the sin column until you are directly opposite 32 degrees, this is the sine value for an angle of 32 degrees. The sine value for 32 degrees is .5299. Let's work another example: Find the sine value of 54 degrees. Because 54 degrees is between 45 and 90 degrees, look in the sixth and twelfth columns (reading up the table) until you locate 54 degrees. Now go to the bottom of the table and to the left find the column labeled "sin". Then go up the sin column until you are directly opposite 54 degrees, this is the sine value for an angle of 54 degrees. The sine value of 54 degrees is .8090.

1-27. If the table does not contain the exact angle or function, we simply take the nearest number.

1-28. Since the trigonometric functions have been defined from the right triangle, the solution of a right triangle problem becomes a simple procedure. By the "solution" of a triangle we mean that we determine unknown sides and unknown angles. In order to solve a right triangle problem, we must know at least two other measurements of the triangle: either two sides or one side and one angle (excluding the right angle). Merely knowing two angles will give us no information about the size of the triangle; we must know at least one side.

Each equation involving a trigonometric ratio, such as:

$$\text{Cos } \theta = \frac{b}{c}$$

contains three quantities. If two of these are given, the third can be determined. Therefore, to solve a specific problem, you must select the trigonometric function which includes the unknown part and the two known parts.

1-29. Refer to figure 1-9 and find angle θ. Since we know the side opposite and the side adjacent, we can use the tangent function to find the angle θ.

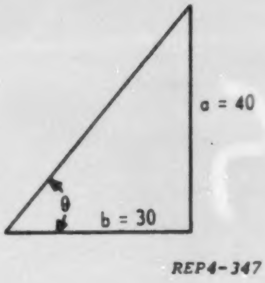


Figure 1-9

Solution:

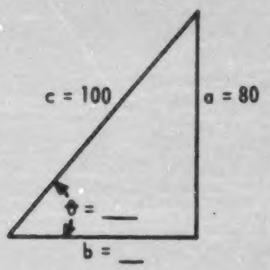
$$\text{Tan } \theta = \frac{\text{Opposite}}{\text{Adjacent}} = \frac{a}{b}$$

$$\text{Tan } \theta = \frac{40}{30}$$

$$\text{Tan } \theta = 1.3333$$

Now look in the Tan column of your Trigonometric Table until you find 1.3333. The exact number is not there; the nearest number is 1.3319, so angle θ is approximately 53.1 degrees.

1-30. Now use the information from figure 1-10 and find angle θ. As we are given the opposite side and the hypotenuse, we can use the sine function to find the value of angle θ.



REP4-348

Figure 1-10

Solution:

$$\text{Sin } \theta = \frac{\text{Opposite}}{\text{Hypotenuse}} = \frac{a}{c}$$

$$\text{Sin } \theta = \frac{80}{100} = .8000$$

$$\text{Sin } \theta = .8000$$

Now look in the Sin column to find .8000. The exact number is not there; but the nearest number is .7997, so angle θ is approximately 53.1 degrees.

1-31. Now that you know the angle, you can find the length of the other side by using the cosine function:

$$\text{Cos } 53.1 \text{ degrees} = \frac{\text{Adjacent}}{\text{Hypotenuse}} = \frac{b}{100}$$

Find the cosine of 53.1 degrees in the table; it is .6004.

Now substitute:

$$.6004 = \frac{b}{100}$$

$$b = 60.04 = 60$$

1-32. Now we are ready to apply angles, triangles, rectangular coordinate systems, and trigonometric functions to solving AC circuit problems.

1-33. Sine wave voltage causes sine wave current in resistive and capacitive circuits. The voltage and current are in phase in purely resistive circuits. This relationship can be expressed by waveshapes, as shown in figure 1-11B; or as vectors shown in figure 1-11C. In figure 1-11B, the waveshape for E_a is the result of adding the waveshapes for E_{R1} and E_{R2} to get E_a. A single vector diagram (figure 1-11c(4) shows this addition. Then we show a vector for total current (I). The current is the same throughout a series circuit. Since voltage and current are in-phase in a resistive circuit, we can display I , E_{R1}, E_{R2}, and E_a on the same line in a vector diagram as shown in figure 1-11C(6). The vector diagrams are much easier to work with than the waveshapes in figure 1-11B.

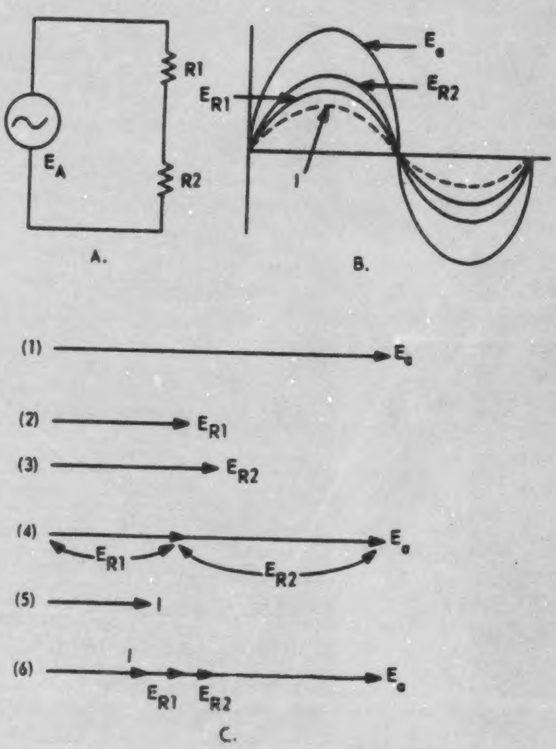


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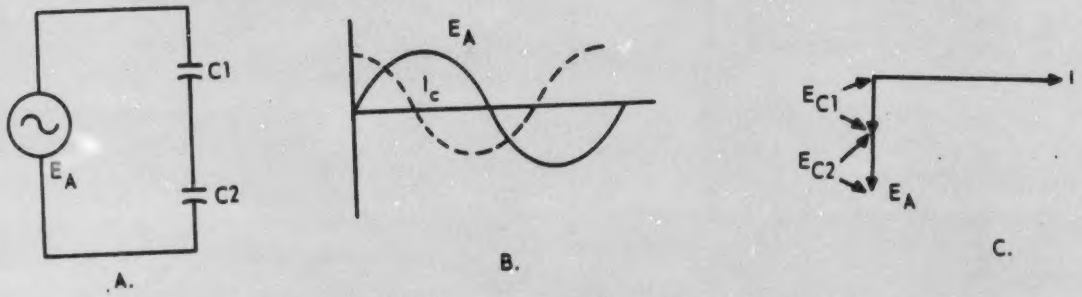
Figure 1-11



REP4-350

Figure 1-12

1-34. In a purely capacitive circuit, the current is 90 degrees ahead of the voltage across the capacitors. These relationships are shown in figure 1-12. The two capacitive voltages added together equal the applied voltage.

1-35. We have represented a pure resistive circuit and a pure capacitive circuit by vectors. Now we are going to represent a series circuit containing both resistance and capacitance by vectors. To start, we must select a common point for both the capacitor and resistor vectors. Since we are working with a series circuit our common point will be current. Why? Because the same current flows throughout a series circuit. I_C, I_R, and I are the same. Knowing this, we can draw the vectors as shown in figure 1-13A.

E_R is on the same line as I because voltage and current are in-phase in a resistor. E_c is 90 degrees behind I as voltage lags current by 90 degrees for a capacitor. E_a is the vector sum of E_R and E_C. Therefore we can draw the vector for E_a as shown in figure 1-13B. We may determine the vector sum through the use of the Pythagorem Theorem.

1-36. Since the voltage drop for a resistor (E_R) is developed across its resistance, we place the vector for R on the same line as E_R. Also, the voltage drop for a capacitor is developed across its capacitive reactance (X_C). Thus we place a vector for X_C on the same line as E_C. This is shown in figure 1-13C. We can also draw a vector for total impedance (Z) on the same line as E_a since applied voltage is felt across the total opposition to current flow in a circuit. We now have a voltage vector diagram showing the current and all voltages and an impedance vector diagram showing all oppositions to current flow.

1-37. The impedance vector diagram was placed on top of the voltage vector diagram to show relationship between voltage and impedance. However, in practical use, we separate the two vector diagrams. The impedance vector diagram is shown in figure 1-14A. For impedance vector diagrams the resistance vector (R) will be the reference and plotted at zero degrees. The impedance angle (θ) is formed by the R and Z vectors.

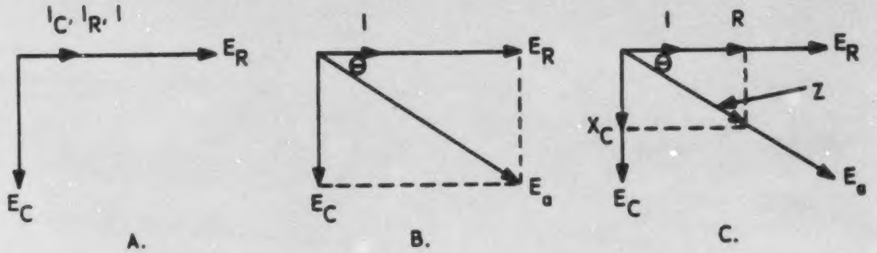


Figure 1-13

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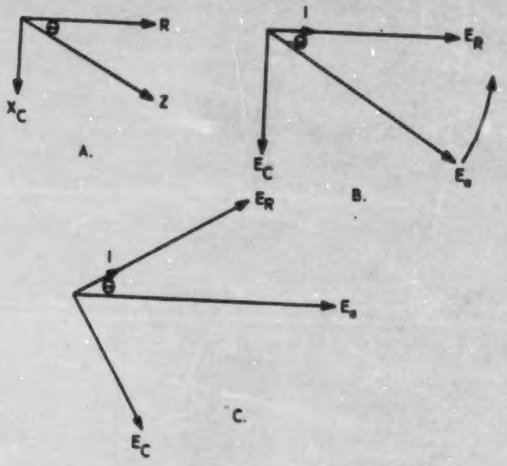

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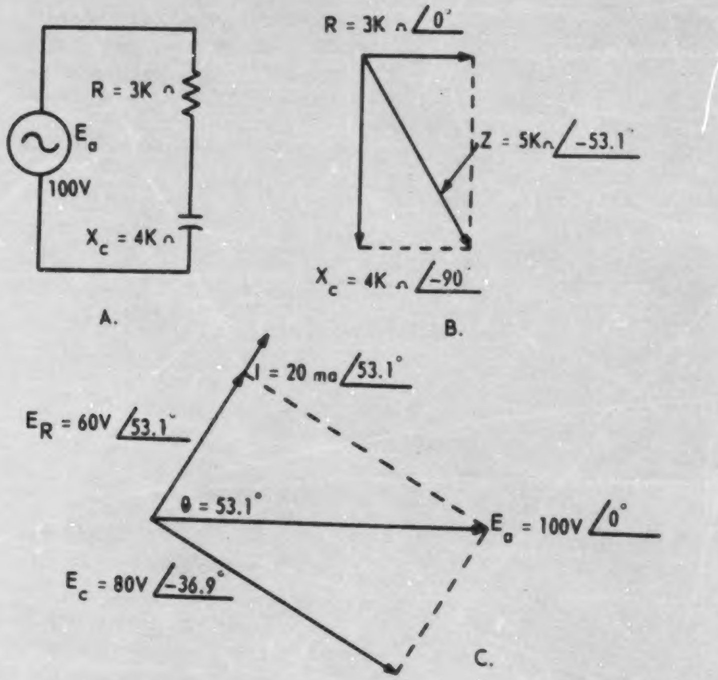
Figure 1-14

1-38. The voltage vector diagram is shown in figure 1-14B. However, for voltage vector diagrams, E_a is used as the reference point and plotted at zero degrees. To do this we simply rotate the voltage vector diagram (in the direction shown in figure 1-14B) until E_a is at the zero degree reference as shown in figure 1-14C. Angle θ is formed by the E_R and I vectors and the E_a vector. This angle tells us how much the total current is leading the applied voltage. It also tells us how much the voltage drop across the resistor is leading the applied voltage. The angle formed by the E_a vector and the E_C vector tells us how much the capacitive voltage is lagging the applied voltage. This angle can be determined by subtracting angle θ from 90 degrees as there is always 90 degrees between E_R and E_C. Notice that angle θ on the impedance vector diagram has the same value as angle θ on the voltage vector diagrams, but has the opposite sign.

1-39. Having combined resistive and capacitive components, we are going to solve series RC circuit problems. Figure 1-15A is a series RC circuit with an AC voltage applied. We are going to solve for total impedance, phase



REP4-351

Figure 1-15

angle, current, and the voltage across each component.

1-40. To determine total impedance, Z, draw an impedance vector diagram as shown in figure 1-15B. Draw the diagram to scale. The 3 k ohm resistor vector is drawn along the zero degree reference line. The 4 k ohm capacitive reactance vector is drawn at -90 degrees. To determine the location of the Z vector, construct a rectangle using the R and X_C vectors as the sides. This is shown by the dotted lines in figure 1-15B. The Z vector is drawn as the diagonal of the rectangle. The length of the Z vector represents the value of Z. Notice in figure 1-15B that Z is the hypotenuse and R and X_C form the sides of a right triangle. To find the value of Z, use the Pythagorean Theorem. The basic formula, $c = \sqrt{a^2 + b^2}$, can be converted to $Z = \sqrt{R^2 + X_C^2}$.

Solution:

$$Z = \sqrt{R^2 + X_C^2}$$

$$= \sqrt{(3 \times 10^3)^2 + (4 \times 10^3)^2}$$

$$= \sqrt{(9 \times 10^6) + (16 \times 10^6)}$$

$$= \sqrt{25 \times 10^6}$$

$$= 5 \times 10^3 \text{ or } 5 \text{ k ohms}$$

1-41. To determine the phase angle between the R vector and the Z vector, use the impedance vector diagram of figure 1-15B and the trigonometric functions. Because we know two sides of the right triangle, R and Z, we can use the cosine function to determine angle θ.

$$\text{Cos } \theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\text{Cos } \theta = \frac{R}{Z}$$

$$\text{Cos } \theta = \frac{3 \text{ k}\Omega}{5 \text{ k}\Omega}$$

$$\text{Cos } \theta = 6000$$

$$\theta = 53.1 \text{ degrees}$$

The exact value of .6000 is not in the trigonometric table, but the nearest value is .6004. So angle θ is approximately 53.1 degrees.

1-42. The complete expression for impedance in this problem is $Z = 5 \text{ k}\Omega \angle -53.1$ degrees. The impedance angle is negative because it is CW from the zero degree reference line. The symbol $\angle$___ is short hand for "an angle of". Figure 1-15B is now complete.

1-43. To determine total current, use Ohms Law for AC circuits. In DC circuits, total current is equal to the applied voltage divided by the total resistance. In AC circuits, total current equals the applied voltage divided by total impedance. In formula form:

$$I = \frac{E_a}{Z}$$

$$I = \frac{100 \text{ V} \angle 0°}{5 \text{ k} \angle -53.1°}$$

$$= 20 \text{ mA} \angle 53.1°$$

1-44. In the formula for current, the voltage was listed at 0 degrees. When drawing voltage vectors, E_a is drawn at the zero reference point. The phase angles for E_R, E_C and I are measured from the E_a vector.

1-45. Phase angles for vectors are treated much like the exponents were treated for powers of ten. To multiply two magnitudes at different angles, add the angles. To divide two magnitudes at different angles, subtract the angle in the denominator from the angle in the numerator. In the previous problem 5 k Ω $\angle -53.1°$ divided into 100 V $\angle 0°$ equals 20 mA $\angle 53.1°$. The positive angle indicates that current is leading the applied voltage by 53.1°. A negative angle would indicate a lagging condition.

1-46. To determine the voltage drop across each component, use Ohms Law.

$$E_R = I\,R$$

$$= (20\text{ mA }\angle\underline{53.1^\circ}) \times (3 \times 10^3\,\Omega\,\angle\underline{0^\circ})$$

$$= 60\text{ V }\angle\underline{53.1^\circ}$$

$$E_C = I\,X_C$$

$$= (20\text{ mA }\angle\underline{53.1^\circ}) \times (4 \times 10^3\,\Omega\,\angle\underline{-90^\circ})$$

$$= 80\text{ V }\angle\underline{-36.9^\circ}$$

1-47. Figure 1-15C shows the complete voltage vector diagram with the current vector included. The voltage across the resistor is in phase with the current; the voltage across the capacitor is 90° behind the current; and the applied voltage is 53.1° behind the current. Notice, that phase angle relationships of the voltage vector diagram are the same as for the impedance vector diagram. When we multiplied each impedance by the current, the diagram of figure 1-15B changes to that of figure 1-15C. Remember that the voltage vector diagram's change in position was caused by rotating it to place E_a at the zero degree reference point.

1-48. Now, let's solve another problem. Refer to figure 1-16. Our first step in solving this problem is to find the voltage drop across the resistor. We use the Pythagorean Theorem to do this. Substitute E_a for side c, E_R for side a, and E_C for side b. Then the formula $a = \sqrt{c^2 - b^2}$, becomes $E_R = \sqrt{(E_a)^2 - (E_C)^2}$.

$$E_R = \sqrt{E_a{}^2 - E_C{}^2}$$

$$E_R = \sqrt{(225)^2 - (180)^2}$$

NOTE: Look in your Electronic Handbook for the squared numbers.

$$E_R = \sqrt{50{,}625 - 32{,}400}$$

$$E_R = \sqrt{18{,}225}$$

NOTE: Look in your Electronic Handbook for the square root.

$$E_R = 135\text{ V}$$

1-49. The next step is to find I. Knowing the voltage drop across the resistor and the size of the resistor, we can calculate current using Ohm's Law because the current is the same throughout a series circuit.

$$I = \frac{E_R}{R} = \frac{135\text{ V}}{9 \times 10^3\,\Omega} = 15\text{ mA}$$

Next X_C can be found:

$$X_C = \frac{E_C}{I} = \frac{180\text{ V}}{15 \times 10^{-3}\text{ A}} = 12\text{ k}\Omega$$

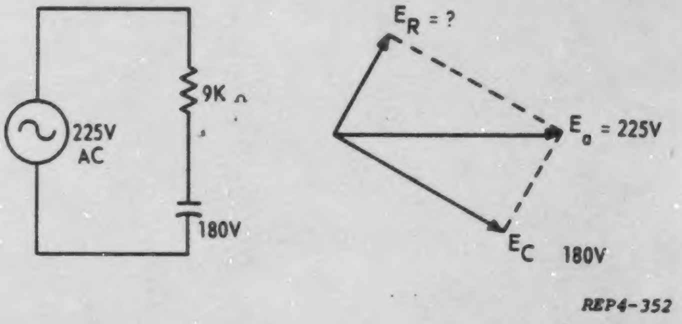


Figure 1-16

Then:

$$Z = \frac{E_a}{I}$$

$$Z = \frac{225\ V}{15 \times 10^{-3}\ A}$$

$$Z = 15 \times 10^{+3}\ \Omega$$

$$Z = 15\ k\Omega$$

1-50. With the impedance information we have we can find angle θ with trigonometric functions.

Using Impedance Vectors

$$\text{Cos}\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\text{Cos}\ \theta = \frac{9\ k\Omega}{15\ k\Omega}$$

$$\text{Cos}\ \theta = .6000$$

$$\theta = 53.1°$$

Using Voltage Vectors

$$\text{Cos}\ \theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\text{Cos}\ \theta = \frac{135\ V}{225\ V}$$

$$\text{Cos}\ \theta = .6000$$

$$\theta = 53.1°$$

1-51. The complete voltage and impedance vector diagrams are shown in figure 1-17. Once we have angle θ, it is simple to calculate the other angles if we remember that E_a and R are plotted at zero degrees and that there are 90 degrees between E_R and E_C and between R and X_C.

1-52. Let work another problem with different values. Refer to figure 1-18.

First step: Use the formula $X_C = \frac{.159}{fC}$ to find X_C.

$$X_C = \frac{.159}{fC} = \frac{.159}{53 \times (.5 \times 10^{-6})} = \frac{.159}{26.5 \times 10^{-6}}$$

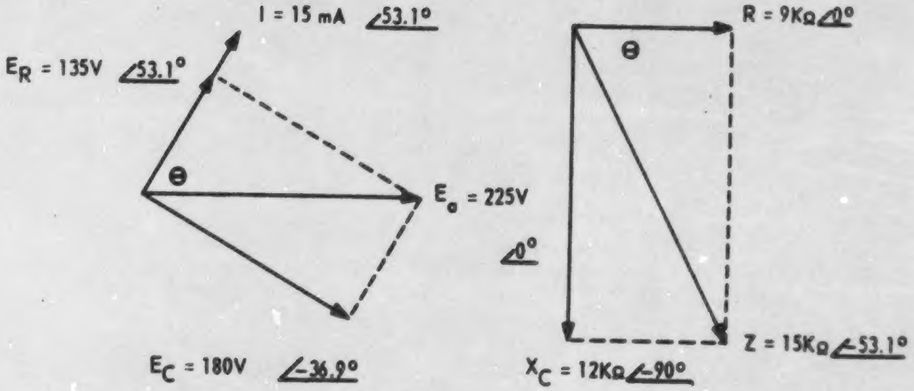


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Figure 1-17

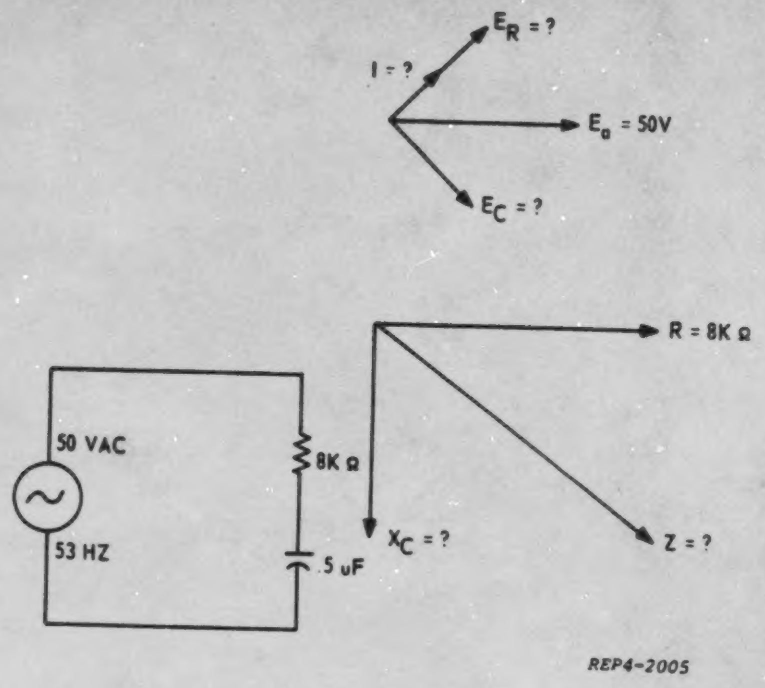


Figure 1-18

$$X_C = \frac{.159 \times 10^6}{26.5} = \frac{159{,}000}{26.5}$$

$$X_C = 6\ k\Omega$$

Next find Z .

$$Z = \sqrt{R^2 + X_C^2}$$

$$Z = \sqrt{(8 \times 10^3)^2 + (6 \times 10^3)^2}$$

$$Z = \sqrt{(64 \times 10^6) + (36 \times 10^6)} = \sqrt{100 \times 10^6}$$

$$Z = 10 \times 10^3 = 10\ k\Omega$$

Third: Find I .

$$I = \frac{E_a}{Z} = \frac{50\ V}{10 \times 10^3 \Omega} = 5 \times 10^{-3} = 5\ mA$$

Fourth: Find the impedance angle.

$$\cos \theta = \frac{R}{z} = \frac{8k\ \Omega}{10k\ \Omega}$$

$$\cos \theta = .8000$$

$$\theta = 36.9°$$

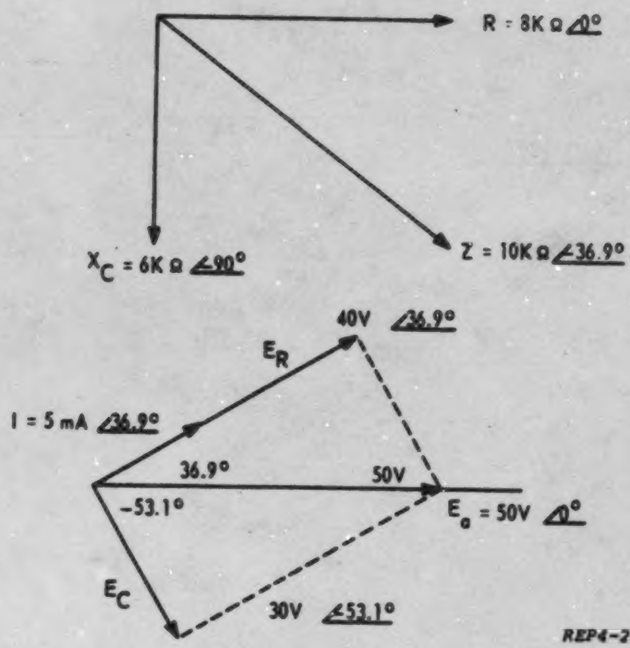
Fifth: Find the voltage drop across the resistor.

$$E_R = I R = (5 \times 10^{-3}) \times (8 \times 10^{+3}) = 40\ V$$

Sixth: Find the voltage drop across the capacitor

$$E_C = I X_C = (5 \times 10^{-3}) \times (6 \times 10^{+3}) = 30\ V$$

Seventh: Plot the voltage and impedance vectors. Refer to figure 1-19.


R = 8K Ω ∠0°
X_C = 6K Ω ∠90°
Z = 10K Ω ∠36.9°
40V ∠36.9°
E_R
I = 5 mA ∠36.9°
36.9°
50V
-53.1°
E_a = 50V ∠0°
E_C
30V ∠53.1°

REP4-2006

Figure 1-19

Chapter 2

SERIES RL AND RCL CIRCUITS

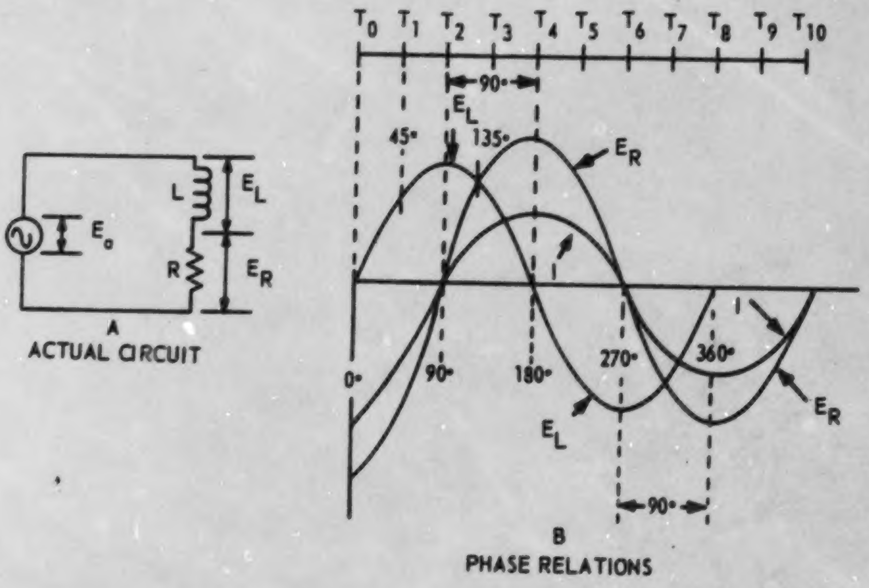
2-1. This lesson covers series RL and RCL circuits. You will determine voltage drops, current, phase angle, and impedance associated with RL and RCL series circuits. You will extend your knowledge of: vector analysis, use of the Pythagorean Theorem, rectangular coordinates, and trigonometric functions as they apply to these circuits.

2-2. Recall that inductance opposes a change in current. The expanding and collapsing magnetic field cuts across the conductors and induces a counter emf (CEMF) which opposes the current change. The opposing force is such that, when a sine wave of voltage is applied, the current through a pure inductance lags E_a by 90°.

2-3. Now consider a simple series circuit (one path for current) which contains a resistor and an inductor. Refer to figure 2-1A. We know that resistor voltage and current are in phase. We also know that the current through the coil lags the voltage across the coil by 90°. These phase relationships are shown in figure 2-1B. At time T_2, the maximum positive voltage appears across the coil; and the current has just begun to flow in the positive direction. Current increases to maximum 90° later at T_4.

2-4. The current and voltage waveshapes across the resistor are in phase. Current lags the voltage across the inductor by 90°. The current in the coil is the same as the current in the resistor. We can plot the voltage vectors with current as the reference (figure 2-2). Figure 2-1 shows E_R larger than E_L. Plot these values and draw the rectangles.

2-5. Connecting points A and B gives the magnitude and direction of the applied voltage. The angle formed by E_a and I is the phase angle θ. The sign of the phase angle depends on the current vector position with reference

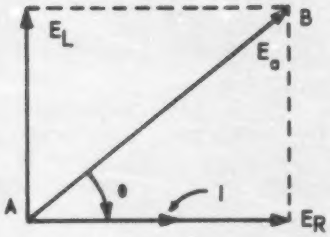

L
R
E_L
E_R
E_a
T_0 T_1 T_2 T_3 T_4 T_5 T_6 T_7 T_8 T_9 T_{10}
90°
45°
135°
I
0°
90°
180°
270°
360°

A
ACTUAL CIRCUIT

B
PHASE RELATIONS

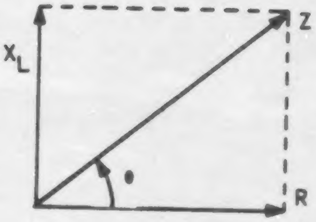
REP4-362

Figure 2-1



REP4-367

Figure 2-2



REP4-364

Figure 2-4

to the applied voltage. The phase angle is negative. Inductive circuit current lags the applied voltage. Using E_a as the reference, the vector diagram would be as shown in figure 2-3. The current vector still has a negative angle. The impedance vector diagram is shown in figure 2-4.

2-6. Note that the impedance angle in the impedance diagram has the same value as the current phase angle in the voltage vector diagram, but the impedance phase angle is positive. Remember the impedance plane angle is measured from the resistance vector.

2-7. Now, let's solve for the unknown values for the circuit of figure 2-5. First, it is wise to look at the known value of any circuit; then decide how to proceed. We find that we have the values of E_a, X_L, and R.

2-8. First, solve for impedance and phase angle.

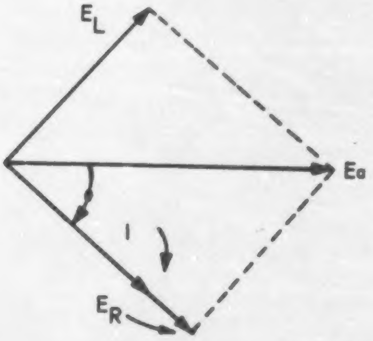
$$Z = \sqrt{R^2 + X_L^{\ 2}}$$

$$Z = \sqrt{R^2 + X_L^{\ 2}} = \sqrt{6^2 + 8^2}$$

$$= \sqrt{36 + 64} = \sqrt{100} = 10 \text{ ohms}$$

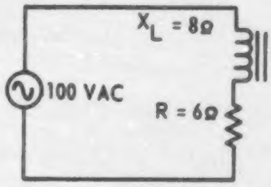
$$\cos \theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{6}{10} = .6000$$

$$\theta = 53.1^\circ$$



REP4-363

Figure 2-3



REP4-365

Figure 2-5

Then solve for current.

$$I = \frac{E_a}{Z}$$

$$I = \frac{100\ \angle 0^\circ}{10\ \angle 53.1^\circ} = 10\text{ A}\ \angle -53.1^\circ$$

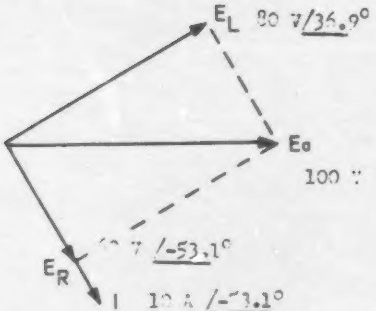
Hence:

$E_R = IR = (10\ \angle -53.1^\circ) \times (6\angle 0^\circ) = 60\text{V}\angle -53.1^\circ$

Then:

$E_L = IX_L = (10\angle -53.1^\circ)\times(8\angle 90^\circ) = 80\text{V}\angle 36.9^\circ$

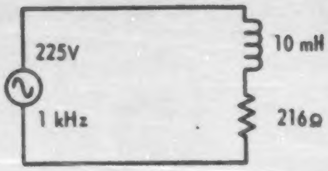
Next plot and label the voltage vectors.



REP4-522

Figure 2-6

2-9. Now, let's solve the circuit shown in figure 2-7.



REP4-366

Figure 2-7

$X_L = 2\pi fL = (6.28)\times(1 \times 10^3)\times(10 \times 10^{-3})$

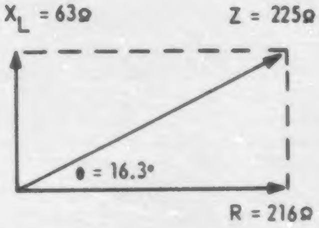
$= 62.8 \text{ or } 63\ \Omega$

$Z = \sqrt{R^2 + X_L^2} = \sqrt{(216)^2 + (63)^2}$

$Z = \sqrt{46{,}656 + 3{,}969} = \sqrt{50{,}625}$

$Z = 225$ ohms

Impedance vectors:



REP4-523

Figure 2-8

$$\text{Cos } \theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{216\Omega}{225\Omega} = .9600$$

$\theta = 16.3^\circ$

$$I = \frac{225\text{V}\angle 0^\circ}{225\Omega\ \angle 16.3^\circ} = 1\text{A}\ \angle -16.3^\circ$$

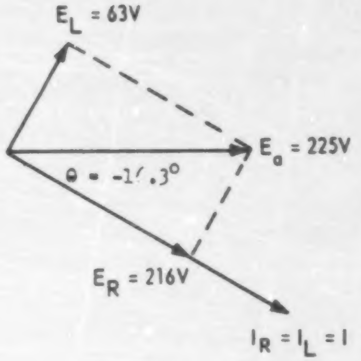
$E_R = I \times R = (1\ \text{A}\ \angle -16.3°) \times (216\,\Omega\ \angle 0°)$

$= 216\text{V}\ \angle -16.3°$

$E_L = I \times X_L = (1\ \text{A}\ \angle -16.3°) \times (63\ \ \angle 90°)$

$= 63\text{V}\ \angle 73.7°$

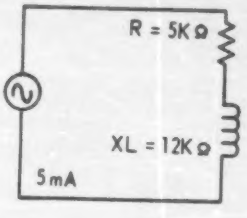
Voltage vectors:


E_L = 63V
E_a = 225V
θ = -16.3°
E_R = 216V
I_R = I_L = I

REP4-524

Figure 2-9

2-10. Let's try one more problem (figure 2-10):


R = 5KΩ
XL = 12KΩ
5mA

REP4-368

Figure 2-10

$$Z = \sqrt{R^2 + X_L^2}$$

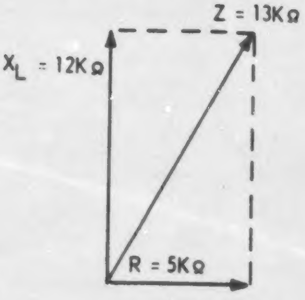
$$= \sqrt{(5 \times 10^3)^2 + (12 \times 10^3)^2}$$

$$= \sqrt{(25 \times 10^6) + (144 \times 10^6)}$$

$$= \sqrt{169 \times 10^6} = 13 \times 10^3$$

= 13 k ohms

Impedance vectors:


Z = 13KΩ
X_L = 12KΩ
R = 5KΩ

REP4-525

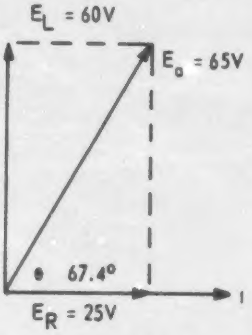
Figure 2-11

$E_a = I\,Z = (5 \times 10^{-3}) \times (13 \times 10^3) = 65\ \text{V}$

$E_L = I\,X_L = (5 \times 10^{-3}) \times (12 \times 10^3) = 60\ \text{V}$

$E_R = I\,R = (5 \times 10^{-3}) \times (5 \times 10^3) = 25\ \text{V}$

Voltage vectors when current is used as the reference:


E_L = 60V
E_a = 65V
θ 67.4°
E_R = 25V
I

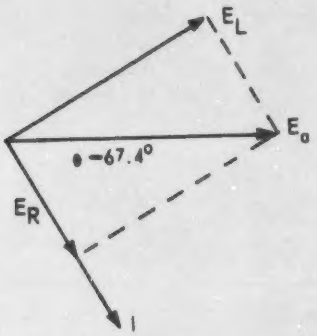
REP4-526

Figure 2-12

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{25}{65} = .3846$$

$\theta = 67.4°$

Voltage vectors when applied voltage is the reference:

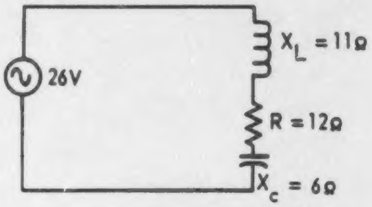


REP4-527

Figure 2-13

In inductive circuits the current always lags the applied voltage. The phase angle is negative.

2-11. The next circuit we will discuss in this lesson is a series RCL circuit, figure 2-14.



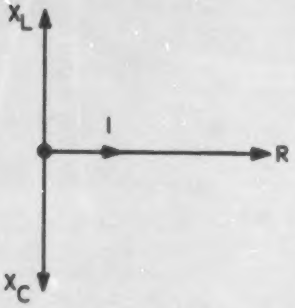
REP4-369

Figure 2-14

2-12. This type circuit contains a resistor, a capacitor, and an inductor connected in series. The capacitive reactance causes the voltage to lag the current. The inductive reactance causes the voltage to lead the current. Thus, the two reactances are opposite in effect; X_L and X_C are 180° out of phase. See figure 2-15.

2-13. If L is in henries, to find X_L, use the formula $X_L = 2\pi fL$. If C is in farads, to find X_C, use the formula

$$X_C = \frac{1}{2\pi fC}$$



REP4-2004

Figure 2-15

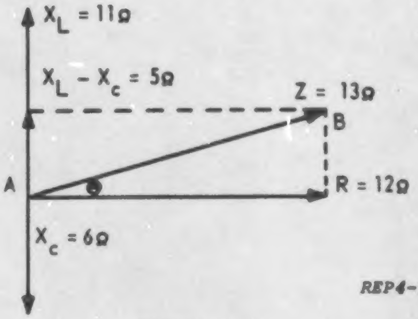
2-14. First draw a vector diagram for the impedance values. See figure 2-16.

2-15. The resistance of the circuit is 12 ohms. This is shown as 12 units on the horizontal axis. As before, plot capacitive reactance at -90° and inductive reactance at +90°. Note that X_L and X_C are 180° out of phase with each other. The net reactance, therefore, is $X_L - X_C$, or 5 ohms of inductive reactance. This is shown as 5 units at $\underline{/+90^\circ}$, because X_L is larger than X_C. The solid line drawn from point A to B is the vector sum of all three values. It represents total opposition to the current flow. Calculate for impedance by using the formula:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

2-16. Find the impedance angle using the vector diagram (figure 2-16):

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{R}{Z} = \frac{12\Omega}{13\Omega} = .9231$$



REP4-370

Figure 2-16

Look in the table (figure 31, KEP 110) to find $\theta = 22.6°$.

$$Z = 13\,\Omega \;\angle 22.6°$$

2-17. Now that we know the impedance, it is an easy matter to find the current. Use Ohm's Law and substitute Z in place of R in the formula.

The formula now becomes:

$$I = \frac{E}{Z} = \frac{26\text{V} \;\angle 0°}{13\,\Omega \;\angle 22.6°} = 2 \text{ amps } \angle -22.6°$$

2-18. Current in a series circuit is the same throughout the circuit; therefore, we can use Ohm's Law to find the voltage drop across each component.

$$E_R = IR = (2\text{ A} \;\angle -22.6°) \times (12\,\Omega \;\angle 0°) = 24 \text{ V } \angle -22.6°$$

This 24 volts across the resistor is lagging E_a by 22.6°. Now to find the voltage drop across the inductor:

$$E_L = IX_L = (2 \text{ A } \angle -22.6°) \times (11\,\Omega \;\angle 90°)$$

$$= 22 \text{ V } \angle 67.4°$$

So, we have 22 volts across the coil. This voltage is leading E_a by 67.4°.

Next, let us find E_C.

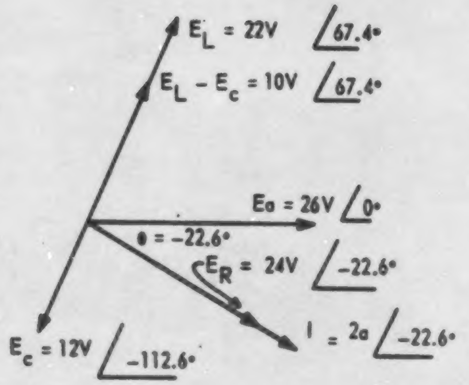
$$E_C = IX_C = (2 \text{ A } \angle -22.6°) \times (6\,\Omega \;\angle -90°)$$

$$= 12 \text{ V } \angle -112.6°$$

There we have 12 volts across the capacitor and this voltage lags E_a by 112.6°.

2-19. It is usually an aid to sketch the vectors as you solve the problem, such as figure 2-17.

2-20. Notice that the current is in phase with the resistor voltage, lags inductor voltage by 90° and leads capacitor voltage by 90°.


E_L = 22V $\angle 67.4°$
$E_L - E_c$ = 10V $\angle 67.4°$
E_a = 26V $\angle 0°$
$\theta = -22.6°$
E_R = 24V $\angle -22.6°$
I = 2a $\angle -22.6°$
E_c = 12V $\angle -112.6°$

REP4-371

Figure 2-17

2-21. The voltage drops across the two reactive components are in opposite directions, or 180° out of phase. This is true in any series AC circuit containing X_L and X_C.

2-22. Figure 2-17 shows the vector sum of E_L and E_C is 10 volts. This vector combined with E_R, which is 24 volts, equals 26 volts. Check for accuracy using the Pythagorean Theorem:

$$E_a = \sqrt{E_R^2 + (E_L - E_C)^2}$$

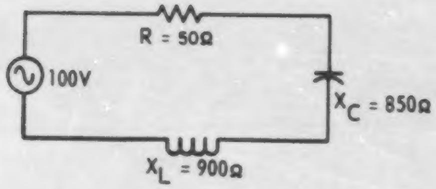
$$E_a = \sqrt{24^2 + (22 - 12)^2}$$

$$E_a = \sqrt{24^2 + 10^2}$$

$$E_a = \sqrt{676}$$

$$E_a = 26 \text{ V}$$

2-23. Let's try another circuit (figure 2-18).



REP4-373

Figure 2-18

In solving this problem subtract the smaller reactance from the larger reactance. In this case, $X_L - X_C$ is 50 ohms. The resulting impedance has the same opposition to AC as a resistor of 50 ohms in series with an inductor having a reactance of 50 ohms.

2-24. Now find the impedance value:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= \sqrt{50^2 + 50^2}$$

$$= \sqrt{5000}$$

$$= 70.7\ \Omega$$

2-25. Next solve for phase angle:

$$\cos\theta = \frac{R}{z} = \frac{50\ \Omega}{70.7\ \Omega} = .7071$$

$$\theta = 45^\circ$$

2-26. Find total current and the voltage across each component.

$$I = \frac{E_a}{Z} = \frac{100\ \text{V}\ 0^\circ}{70.7\Omega\ \underline{/45^\circ}} = 1.4\ \text{amps}\ \underline{/-45^\circ}$$

$$E_R = I\,R = (1.4\text{A}\ \underline{/-45^\circ}) \times (50\ \Omega\ \underline{/0^\circ})$$

$$= 70\ \text{V}\ \underline{/-45^\circ}$$

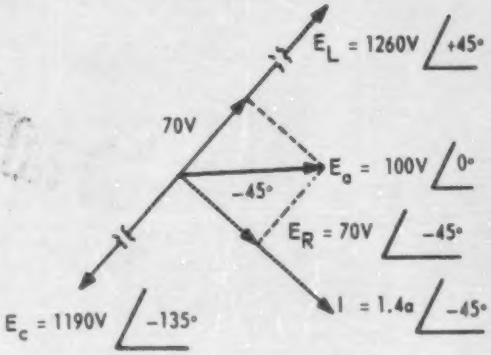
$$E_C = I\,X_C = (1.4\ \text{A}\ \underline{/-45^\circ}) \times (850\ \Omega\ \underline{/-90^\circ}$$

$$= 1190\ \text{V}\ \underline{/-135^\circ}$$

$$E_L = I\,X_L = (1.4\ \text{A}\ \underline{/-45^\circ}) \times (900\ \Omega\ \underline{/90^\circ})$$

$$= 1260\ \text{V}\ \underline{/45^\circ}$$

2-27. Now we can plot the voltage vectors to see their relative positions and phase relationships. Refer to figure 2-19.



REP4-374

Figure 2-19

2-28. Observe that the voltage across the coil and capacitor are much larger than the applied voltage. Since these values are in opposite directions (180° out of phase), the effective voltage across the two reactances is 70 volts. The vector sum of reactive and resistive voltage equals the applied voltage.

Chapter 3

SERIES RC, RL, AND RCL CIRCUITS

3-1. This lesson discusses the factors affecting power in series RC, RL and RCL circuits.

3-2. Remember that power is defined as the "rate of doing work" Electrically, it is expressed in watts, or in kilowatts (thousands of watts).

3-3. In DC, or purely resistive AC circuits, power is simple to calculate. Current is maximum when the voltage is maximum; or in other words, current and voltage are in phase. Power equals voltage times current. Maximum power is delivered to the load.

3-4. However, in reactive circuits, current will be either leading or lagging the applied voltage. That is, the current and applied voltage are out of phase. Power delivered to the load is not equal to applied voltage times current.

3-5. Figure 3-1 illustrates current, voltage, and power in an AC resistive circuit. The waveforms indicate instantaneous values.

3-6. Em and Im denote maximum or peak values of voltage and current, respectively. Note that voltage and current reach their maximum positive (above the zero line) and maximum negative (below the zero line) peaks together (in-phase).

3-7. Note that the power pulses are all positive. It's simple to understand when you remember algebraic multiplication. (A negative times a negative equals a positive). Resistive power gives off heat or light or is used in doing other "work." This is called true power, P_t.

3-8. In the case of resistive AC circuits, true power can be found by the following formulas:

$$P_t = E \times I$$

$$P_t = I^2 \times R$$

$$P_t = \frac{E^2}{R}$$

3-9. Figure 3-1 shows Pm as the peak power when peak values of current and voltages are multiplied. Calculating with effective (rms) values of voltage or current results in average power P_{av}

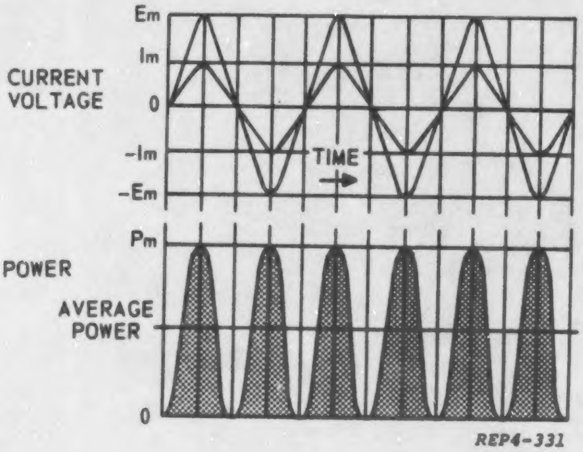


Figure 3-1

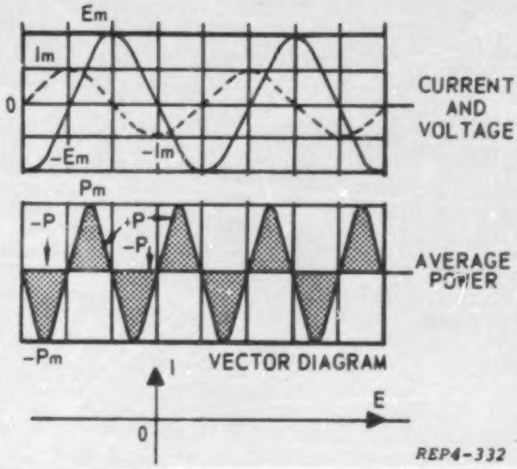


Figure 3-2

3-10. Now, note figure 3-2. It represents current, voltages, and power in a purely capacitive circuit.

3-11. The product of instantaneous values of the 90° out-of-phase values of current and voltage gives a waveform having positive and negative values. (Multiplying like signs gives plus, and unlike signs gives minus). Changing every quarter cycle, figure 3-2 shows first positive current and negative voltage; then both are positive; then positive voltage and negative current; then both are negative. You can see that the average power in a purely capacitive circuit is zero (equal amounts above and below the zero reference line).

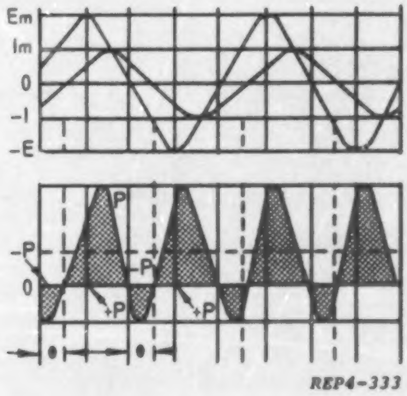


Figure 3-3

3-12. What is actually happening is that the capacitor stores energy on one half alternation; it returns it on the next half alternation. So, no energy is ACTUALLY used, although there is an APPARENT expenditure of energy. This apparent expenditure of energy is called apparent power, P_a.

3-13. The same operation takes place in a purely inductive circuit. The coil stores energy on one half alternation, and returns it on the next half alternation. The average power of a purely inductive circuit is zero.

3-14. Figure 3-3 shows the current, voltage, and power relationships in a circuit containing resistance and inductance. (The same type of analysis could be applied to a resistance-capacitance circuit; except that current leads the voltage across the capacitor).

3-15. In figure 3-3 the voltage leads the current by an angle equal to theta (θ). Since the voltage leads current by the phase angle, there is a period (equal to the phase angle) when the product of E and I is negative. This is the period of time when stored energy is returned to the circuit from the coil.

3-16. You know how to find impedance values, voltage drops, currents, and phase angles, in RC, RL, and RCL series circuits. If you have forgotten, review now before proceeding further.

3-17. Now you can say that in an AC circuit two types of power are known to exist. These are true power (P_t), and apparent power (P_a).

3-18. Let's give these two terms a definition: True Power is the actual power dissipated by the resistance of the circuit and is expressed in watts. An example is power loss in the form of heat. Apparent Power is the product of current and voltage, and is expressed in volt-amperes. The reactive components of a circuit "apparently" dissipate power; but actually do not.

Expressed as equations:

$$P_t = E_R \times I$$

$$P_t = (I_R)^2 \times R$$

$$P_t = \frac{(E_R)^2}{R}$$

$$P_a = E_a \times I$$

$$P_a = (I_t)^2 \times Z$$

$$P_a = \frac{(E_a)^2}{Z}$$

Where:

P_t is true power expressed in watts.

P_a is apparent power expressed in volt-amperes

E_a is applied voltage

Z is impedance

E_R is voltage across circuit resistance

3-19. Now you know the difference between true power and apparent power; let's work problems concerning true power and apparent power.

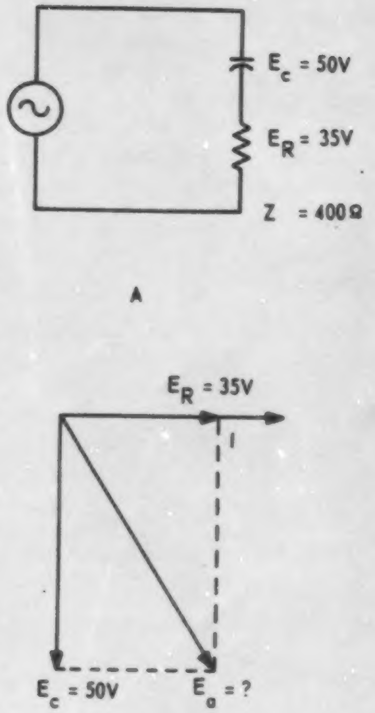
3-20. In the circuit of figure 3-4, determine P_a and P_t.

Solution: Draw two vectors to represent E_R and E_C. (Refer to figure 3-4).

First, solve for E_a:

$$E_a = \sqrt{E_R{}^2 + E_C{}^2} = \sqrt{35^2 + 50^2}$$

$$= \sqrt{3725} = 61V$$



A

B

REP4-334

Figure 3-4

Now, solve for current:

$$I = \frac{E_a}{Z} = \frac{61\ V}{400\ \Omega} = 152.5\ mA$$

Next, solve for apparent power:

$$P_a = E_a I = 61\ V \times 152.5\ mA = 9.3\ VA$$

Finally, solve for true power

$$P_t = E_{R1} \times I = 35V \times 152.5\ mA = 5.34 \text{ watts}$$

3-21. A reactive element in a circuit requires power which is not dissipated. If we add an opposite element to balance out the reactive effect (i.e., add X_L equal to X_C so that $X_C = X_L$), the circuit becomes purely resistive; and all power is dissipated.

3-22. With these facts in mind, let's proceed to the next item of discussion. This is the Power Factor or PF.

3-23. Power Factor is the ratio between true power and apparent power.

$$\text{Power Factor} = \frac{\text{true power}}{\text{apparent power}} \text{ or } PF = \frac{P_t}{P_a}$$

$$\text{Apparent Power} = \frac{\text{true power}}{\text{power factor}} \text{ or } P_a = \frac{P_t}{PF}$$

or, we can also say that:

True power = Apparent power x Power Factor

or $P_t = P_a \times PF$

3-24. Let's review vector diagrams to better understand the phase relationships. Given an RL circuit, we can plot the vector diagrams (figure 3-5).

3-25. If impedance is multiplied by current, we obtain the voltage drop across the impedance. We can apply this to the vector diagrams of figure 3-5. First, multiply each IMPEDANCE vector by the current, and we have a VOLTAGE vector diagram.

3-26. Now, multiply each voltage vector by current and what do we have? Power, of course.

$$E_a I = P_a$$

$$E_R I = P_t$$

$$E_L I = P \text{ (reactive)}$$

3-27. We can plot these values, using current as the reference; we see the power relationship. The vector sum of resistive power (P_t) and reactive power is apparent power. The ratio of true power to apparent power, is defined as power factor; it is also the cosine of the phase angle.

3-28. We can use the vector diagrams and express power factor in four ways:

$$PF = \frac{P_t}{P_a}$$

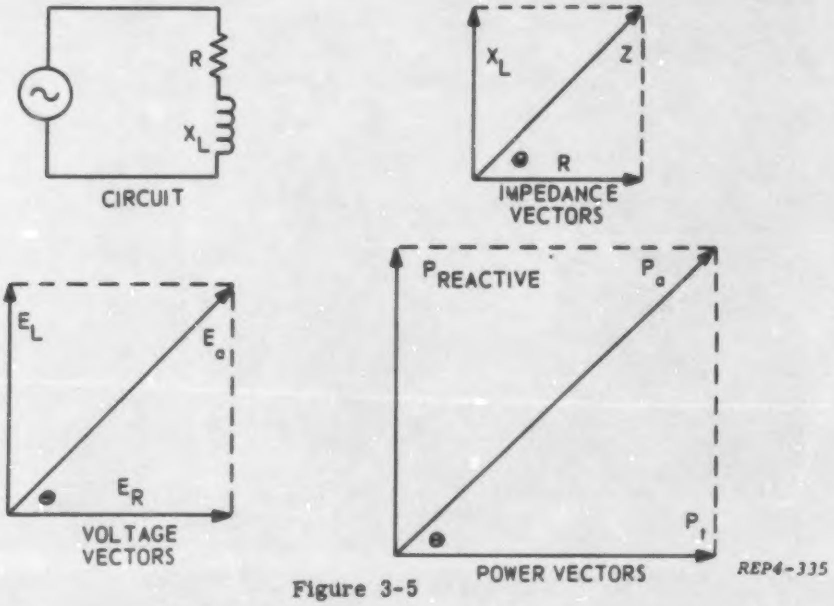


Figure 3-5

$$PF = \frac{E_R}{E_a}$$

$$PF = \frac{R}{Z}$$

$$PF = \text{Cos } \theta$$

3-29. Now let's work some problems to apply these principles: A circuit has an apparent power of 500 volt-amperes and a power factor of .7071. What is the true power?

$$P_t = P_a \times PF = 500VA \times .7071 = 353.55 \text{ watts}$$

You can see it's easy to find the true power when P_a and PF are known. To check this answer: divide true power by power factor $(\frac{P_t}{PF})$ and the answer will be APPARENT POWER, 500 volt-amps. Now, proceed to find PF. Use the same figures that were used for P_t and P_a.

$$\text{Power Factor} = \frac{\text{True Power}}{\text{Apparent Power}}$$

$$PF = \frac{353.55 \text{ watts}}{500 \text{ volt-amps}} = .7071$$

Expressed as a percent this power factor equals 70.7%.

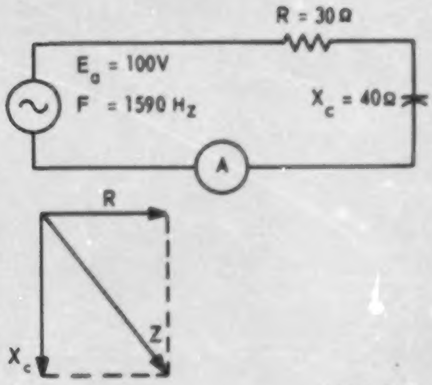
3-30. Let's solve another problem. Using figure 3-6, solve for impedance, phase angle, power factor, current, apparent power, and true power.

$$Z = \sqrt{R^2 + X_C^2}$$

$$Z = \sqrt{900 + 1600}$$

$$Z = 50\,\Omega$$

At what angle is the 50 ohms of impedance? Use the COSINE FUNCTION to find out.



REP4-336

Figure 3-6

$$\text{Cos } \theta = \frac{R}{Z} = \frac{30\,\Omega}{50\,\Omega} = .6000$$

$$\theta = 53.1°$$

Also the power factor is equal to the cosine of the angle θ.

$$PF = \text{Cos } \theta$$

$$PF = .6000 \text{ or } 60\%$$

Continuing with the problem:

$$I = \frac{E_a}{Z} = \frac{100\,\angle 0°}{50\,\angle -53.1°} = 2 \text{ amps } \angle +53.1°$$

$$P_a = E_a I = 100 \text{ V} \times 2 \text{ A} = 200 \text{ volt-amperes}$$

$$P_t = P_a \text{ Cos } \theta = 200 \text{ VA} \times .6 = 120 \text{ watts}$$

3-31. For figure 3-7, first find Z by the Pythagorean Theorem:

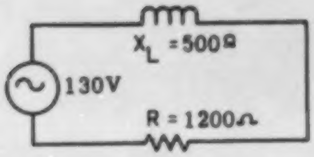
$$Z = \sqrt{(12 \times 10^2)^2 + (5 \times 10^2)^2}$$

$$= \sqrt{144 \times 10^4 + 25 \times 10^4}$$

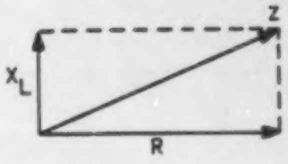
$$= \sqrt{169 \times 10^4}$$

$$= 13 \times 10^2 \text{ or } 1300\,\Omega$$

12



$X_L = 500\Omega$
130V
$R = 1200\Omega$



REP4-337

Figure 3-7

Then solve for current:

$$I = \frac{E_a}{Z}$$

$$= \frac{130\ V}{1300\ \Omega}$$

$$= .1\ A$$

Now calculate apparent power:

$$P_a = E_a I$$

$$= 130\ V \times .1\ A$$

$$= 13\ VA$$

Now we are ready for true power:

$$P_t = I^2 R$$

$$= (.1\ A)^2\ 1200\ \Omega$$

$$= .01 \times 1200$$

$$= 12\ W$$

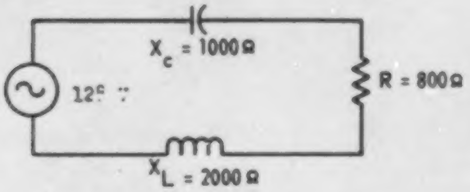
Finally solve for PF:

$$PF = \frac{P_t}{P_a}$$

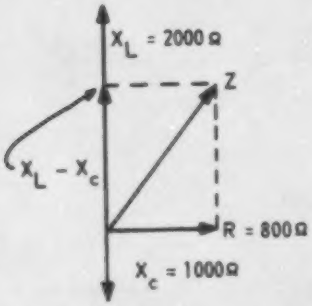
$$= \frac{12\ W}{13\ VA}$$

$$= .9231$$

3-32. If you have an RCL circuit, you can use the same method for finding P_t, P_a, and PF. But you must first find the difference between X_L and X_C. See figure 3-8.



$X_c = 1000\Omega$
128 V
$R = 800\Omega$
$X_L = 2000\Omega$



$X_L = 2000\Omega$
Z
$X_L - X_c$
$R = 800\Omega$
$X_c = 1000\Omega$

REP4-338

Figure 3-8

First, we will take $X_L - X_C$ (2000 - 1000). This gives us a net reactance of $X_L = 1000$ ohms in series with R = 800 ohms.

Now solve for Z:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= \sqrt{(800)^2 + (1000)^2}$$

$$= \sqrt{164 \times 10^4}$$

$$= 1280\ \Omega$$

Next determine current:

$$I = \frac{E_a}{Z} = \frac{128V}{1280\,\Omega}$$

$$= .1A$$

Now calculate P_a:

$$P_a = E_a \text{ X } I = 128V \times .1A$$

$$= 12.8 \text{ VA}$$

Next solve for P_t:

$$P_t = I^2 \times R = (.1A)^2 \times 800$$

$$= .01 \times .800$$

$$= 8 \text{ W}$$

Finally determine PF:

$$PF = \frac{8W}{12.8 \text{ VA}}$$

$$= .6259$$

Chapter 4

PARALLEL RC, RL, AND RCL CIRCUITS

4-1. We learned many things in studying DC parallel circuits that we can apply to AC parallel circuits. We found that the applied voltage is common to all components and total current is the sum of the branch currents. In AC parallel circuits voltage is common to all branches and total current is the VECTOR sum of the branch currents.

4-2. As you know, current leads voltage across a capacitor by 90°. In a coil, current lags the voltage across the coil by 90°. This chapter discusses current, voltage, and power relationships in parallel RC, RL, and RCL circuits.

4-3. Let's use a parallel RCL circuit, as shown in figure 4-1. Observe that the applied voltage (E_a) is common to the resistor, capacitor, and coil. We will plot the various current vectors with reference to the applied voltage.

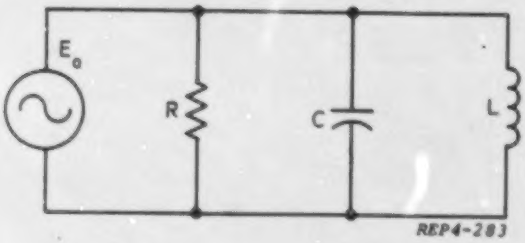


Figure 4-1

4-4. We know that the current through a resistor is in phase with the resistor voltage. So the vectors are as shown in figure 4-2.

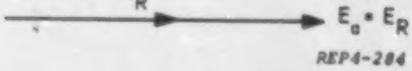


Figure 4-2

4-5. The current through a capacitor leads the capacitor voltage by 90°. The vectors are as shown in figure 4-3.

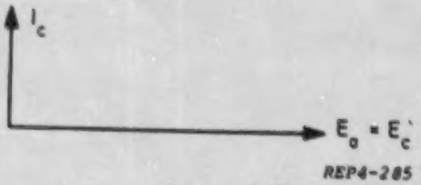


Figure 4-3

4-6. The current through a coil lags the inductor voltage by 90°. The vectors are as shown in figure 4-4.

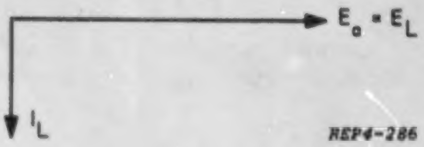


Figure 4-4

4-7. If we plot all three vectors on the same reference, we have a vector diagram for a parallel RCL circuit. Refer to figure 4-5.

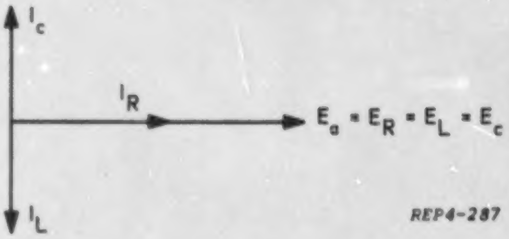


Figure 4-5

4-8. Now, we will discuss how to solve for branch currents, total current, total impedance, and phase angle (Theta θ).

4-9. Let's solve for these values in the parallel circuit illustrated in figure 4-6.

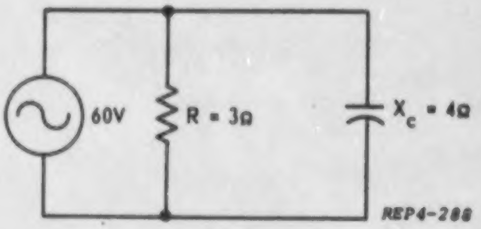


Figure 4-6

4-10. The applied 60 volts is felt across the resistor; it is likewise felt across the capacitor. We can use Ohm's Law to find I_R and I_C.

$$I_R = \frac{E_R}{R} = \frac{60\text{ V}\angle 0^\circ}{3\,\Omega\angle 0^\circ} = 20\text{ amps}\angle 0^\circ$$

$$I_C = \frac{E_C}{X_C} = \frac{60\text{ V}\angle 0^\circ}{4\,\Omega\angle -90^\circ} = 15\text{ amps}\angle 90^\circ$$

4-11. We have 20 amps through the resistor and 15 amps through the capacitor. Now, we must observe the phase relationships of these currents. The total current is the vector sum of the individual branch currents. Take a look at the vectors that represent the current in our circuit in figure 4-7.

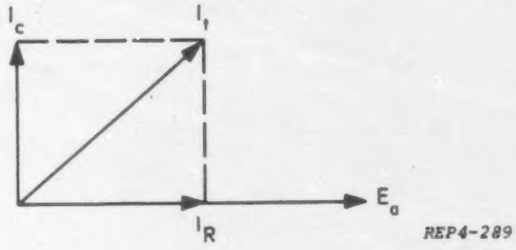


Figure 4-7

4-12. Current through the capacitor and current through the resistor are 90° out of phase. To add the vectors, we complete a parallelogram as shown by the broken lines; the resultant is total current. The value of I_t can be determined by measuring the length of the I_t vector. The phase angle between I_t and I_R can be measured with a protractor. We can also find the value of I_t by applying the Pythagorean Theorem:

$$I_t = \sqrt{I_R^2 + I_C^2} = \sqrt{(20)^2 + (15)^2}$$

$$= \sqrt{400 + 225} = \sqrt{625} = 25\text{ amps}$$

4-13. To find total impedance, use Ohm's Law, substituting Z for R.

$$Z = \frac{E_a}{I_t} = \frac{60\text{ V}}{25\text{ A}} = 2.4\text{ ohms}$$

4-14. You should have noticed that I_t is larger than I_C or I_R but smaller than the arithmetic sum of I_C and I_R. Also total impedance is smaller than the smallest resistor or reactance value in the circuit.

4-15. To solve for the phase angle, we can use the cosine function.

$$\cos\theta = \frac{I_R}{I_t} = \frac{20\text{ A}}{25\text{ A}} = .8000$$

$$\theta = 36.9^\circ$$

4-16. RL circuits are solved in a like manner. Refer to figure 4-8.

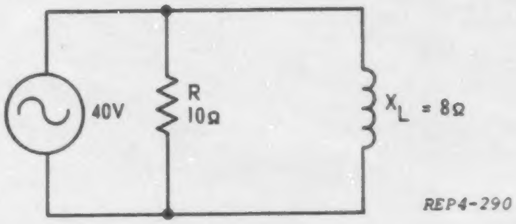


Figure 4-8

$$I_R = \frac{E_a}{R} = \frac{40\text{ V}\angle 0^\circ}{10\,\Omega\angle 0^\circ} = 4\text{ amps}\angle 0^\circ$$

$$I_L = \frac{E_a}{X_L} = \frac{40\text{ V}\angle 0^\circ}{8\,\Omega\angle 90^\circ} = 5\text{ amps}\angle -90^\circ$$

4-17. Remember, current in an inductive circuit (I_L) is 90° behind E_R. This is shown in the vector diagram in figure 4-9.

Total current is the vector sum of I_L and I_R. We can use the Pythagorean Theorem to solve for I_t.

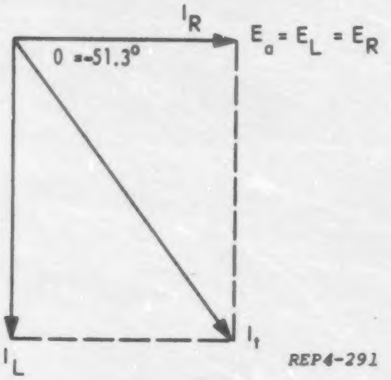


Figure 4-9

$$I_t = \sqrt{I_R^2 + I_L^2} = \sqrt{(4)^2 + (5)^2}$$

$$= \sqrt{16 + 25} = \sqrt{41} = 6.4 \text{ amps}$$

4-18. To solve for total impedance, we use Ohm's Law.

$$Z = \frac{E_a}{I_t} = \frac{40 \text{ V}}{6.4 \text{ A}} = 6.25 \text{ ohms}$$

4-19. Total impedance in a parallel RL circuit is less than the value of X_L or R.

4-20. Last, we will find the phase angle.

$$\text{Cos } \theta = \frac{I_R}{I_t} = \frac{4 \text{ A}}{6.4 \text{ A}} = .6250$$

$$\theta = 51.3°$$

4-21. Now, we should be able to solve a circuit containing a coil, resistor, and capacitor (RCL circuit). Refer to figure 4-10.

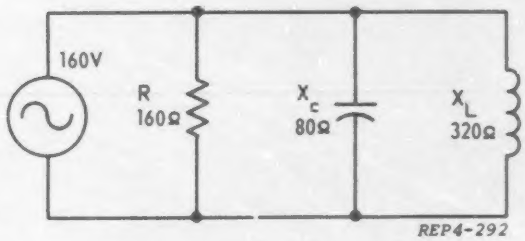


Figure 4-10

4-22. The work for this circuit is easy; find the branch currents first by Ohm's Law.

$$I_R = \frac{E_a}{R} = \frac{160 \text{ V} \angle 0°}{160\ \Omega \angle 0°} = 1 \text{ amp} \angle 0°$$

$$I_C = \frac{E_a}{X_C} = \frac{160 \text{ V} \angle 0°}{80\ \Omega \angle -90°} = 2 \text{ amps} \angle 90°$$

$$I_L = \frac{E_a}{X_L} = \frac{160 \text{ V} \angle 0°}{320\ \Omega \angle 90°} = .5 \text{ amps} \angle -90°$$

4-23. The vectors for this look like figure 4-11.

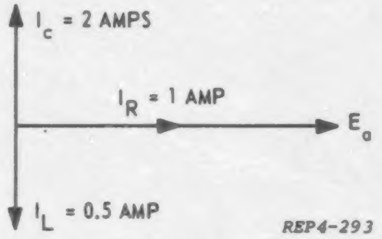


Figure 4-11

4-24. Use Pythagorean Theorem to solve for total current. You must SUBTRACT the smaller reactive current from the larger reactive current to solve this type problem.

$$I_t = \sqrt{I_R^2 + (I_C - I_L)^2}$$

$$= \sqrt{(1)^2 + (2 - .5)^2} = \sqrt{(1)^2 + (1.5)^2}$$

$$= \sqrt{1 + 2.25} = \sqrt{3.25} = 1.8 \text{ amps}$$

4-25. Solve for the phase angle.

$$\text{Cos } \theta = \frac{I_R}{I_t} = \frac{1 \text{ A}}{1.8 \text{ A}} = .555$$

$$\theta = 56.3°$$

4-26. Vectors for this solution are shown in figure 4-12.

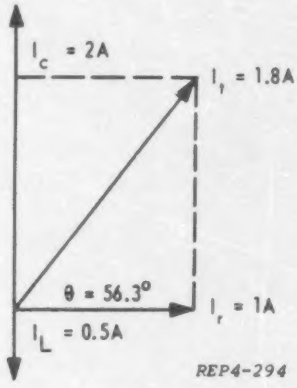


Figure 4-12

4-27. Let's analyze another circuit. Refer to figure 4-13.

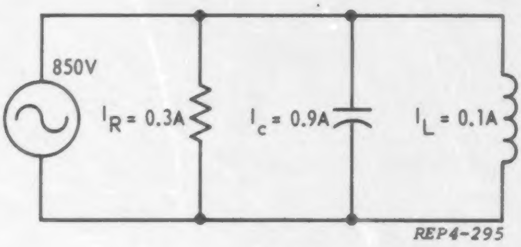


Figure 4-13

4-28. Let's first find I_t and then determine total impedance. Individual branch impedances can be solved using Ohm's Law.

$$I_t = \sqrt{I_R^{\,2} + (I_C - I_L)^2}$$

$$= \sqrt{(.3)^2 + (.9 - .1)^2}$$

$$= \sqrt{(.3)^2 + (.8)^2} = \sqrt{.09 + .64}$$

$$= \sqrt{.73} = .85 \text{ amps}$$

Then:

$$Z = \frac{E_a}{I_t} = \frac{850 \text{ V}}{.85 \text{ A}} = 1000 \text{ ohms}$$

4-29. When the applied voltage is not given, you can solve for total impedance by using the assumed voltage method. If the applied voltage is not given, then assume a voltage and calculate the current through each branch of the circuit. Combine the branch currents using Pythagorean Theorem (or vectors) to determine total current. Use total current and the assumed voltage to calculate the impedance. Regardless what voltage is assumed, the impedance will be correct because impedance is a ratio of current to voltage.

4-30. Let us again refer to figure 4-10. In this circuit total current was 1.8 A. Using Ohm's Law solve for Z .

$$Z = \frac{E_a}{I_t} = \frac{160 \text{ V}}{1.8 \text{ A}} = 88.8\ \Omega$$

Now let us take the same circuit, but arbitrarily pick a different applied voltage. In this case use an assumed voltage of 480 volts. Following the procedure for the assumed voltage method, first calculate the individual branch currents and then determine I_t.

First:

$$I_R = \frac{E_a}{R} = \frac{480 \text{ V}}{160\ \Omega} = 3\text{A}$$

$$I_C = \frac{E_a}{X_C} = \frac{480 \text{ V}}{80\ \Omega} = 6\text{A}$$

$$I_L = \frac{E_a}{X_L} = \frac{480 \text{ V}}{320\ \Omega} = 1.5 \text{ A}$$

Then:

$$I_t = \sqrt{(I_R)^2 + (I_C - I_L)^2}$$

$$= \sqrt{3^2 + (6 - 1.5)^2}$$

$$= \sqrt{9 + 4.5^2}$$

$$= \sqrt{9 + 20.25}$$

$$= \sqrt{29.25}$$

$$= 5.408 \text{ A}$$

4-31. Now use I_t to solve for Z .

$$Z = \frac{E_a}{I_t} = \frac{480 \text{ V}}{5.408 \text{ A}} = 88.8 \ \Omega$$

Notice that the impedance is the same value obtained when the value of the applied voltage was known. This method may also be applied to parallel RC and RL circuits.

4-32. Now, let's discuss power and power factor in parallel reactive circuits. Remember, purely reactive components do not dissipate power. Only the resistance in a circuit dissipates power. This is called true power.

4-33. When reactive components and resistive components are connected in a circuit, the circuit appears to use more power than it actually dissipates. This is called the apparent power of the circuit.

4-34. Apparent power (P_a) of a parallel RCL circuit is: $P_a = E_a I_t$. The formula for true power (P_t) is: $P_t = E_R I_R$. Power factor (PF) is: $PF = \frac{P_t}{P_a}$.

4-35. Using figure 4-13, determine P_a, P_t, PF, and the phase angle θ.

$$P_a = E_a I_t = 850 \text{ V} \times .85 \text{ A} = 722.5 \text{ VA}$$

$$P_t = E_R I_R = 850 \text{ V} \times .3 \text{ A} = 255.0 \text{ watts}$$

$$PF = \frac{P_t}{P_a} = \frac{255 \text{ W}}{722.5 \text{ VA}} = .3529 \text{ or } 35\%$$

$$\cos \theta = .3529$$

$$\theta = 69.30^\circ$$

4-36. Important principles to keep in mind when solving simple parallel RCL circuits:

1. Branch currents may be different, but voltage is the same across all components.

2. Vector diagrams use voltage as the reference, with currents added vectorially.

3. Do not attempt to draw impedance diagrams for parallel circuits.

4-37. Component Testing

4-38. Now, let's discuss how to determine whether a capacitor is good, opened, or shorted. A capacitor that is opened, shorted, or partially shorted (leaky) is useless because the basic function of storing a charge is lost. A leaky capacitor is one in which the dielectric has lost its insulating ability under the constant pressure of the applied voltage. A leaky capacitor will have a low resistance value. A good capacitor of paper or ceramic will have resistance readings upward of 1000 megohms, which for our purposes can be considered to be infinite resistance.

4-39. Generally a capacitor can be checked with an ohmmeter. Before you use the ohmmeter you must disconnect the capacitor from the circuit and make sure the capacitor is fully discharged. The ohmmeter will supply the voltage for checking the capacitor. Keep your fingers off of the connections since body resistance will give erroneous indications. Always use the highest scale on the ohmmeter when checking capacitors.

4-40. When you connect the ohmmeter across a good capacitor, you will get momentary deflection of the meter and then the indicator will return to infinity. This is caused by the charging action of the capacitor. With some capacitors it is difficult to detect this momentary deflection. In this case a practical check is to replace the capacitor with one that you know is good.

4-41. When subjected to high voltages capacitors may arc through the dielectric, causing a short. A short can also be caused by age or high temperatures. When you connect an ohmmeter across a shorted capacitor the meter indicator will deflect to zero. This is a sure indication of a shorted capacitor.

4-42. When you connect an ohmmeter across an open capacitor the indicator will remain at the inifinite reading. Some precaution must be exercised because a very high resistance reading is normal for capacitors. In addition, we must remember that small valued capacitors do not need much charging current and therefore will not show a deflection on the meter. As a result care must be exercised when checking capacitors for opens. In these cases it may be more practical to substitute a new capacitor.

4-43. Inductors, like capacitors, can be checked using an ohmmeter. You must remember that in using an ohmmeter to check coils you are measuring the DC resistance of the coil. The coil normally has very low resistance. This presents a problem when troubleshooting coils.

4-44. A common trouble with coils is an open. This type of trouble is easy to find because it lacks continuity. When an ohmmeter is placed across a coil with an open the meter will indicate an infinite ohms. The open inductor may be caused by corrosion, excessive current, or age. Small wire can be easily damaged.

4-45. Unlike opens, shorts in inductors are difficult to locate. When an ohmmeter is placed across an inductor that is shorted, the meter will indicate zero ohms. Care must be exercised. Remember that some coils have just a few turns of wire and normally show a zero ohm reading. It is rare that you will have a completely shorted inductor. Normally just a few turns short together. This condition cannot be definitely checked with an ohmmeter because the resistance will change only slightly. When troubleshooting a coil that is suspected of having a short, the best check is to substitute a new coil.

Chapter 5

SERIES RESONANCE

5-1. This chapter is a continuation of your study of the series RCL circuit. In the last lesson, inductive reactance and capacitive reactance had opposing impedance effects. If the frequency applied to a series RCL circuit causes X_C and X_L to be equal, the circuit is resonant. In this chapter, we study the conditions which exist when a series circuit is RESONANT. Then, we analyze circuit operation by varying frequency and impedance values above and below the resonant point. We will discuss BANDWIDTH and SELECTIVITY.

5-2. Resonant circuits are used in radar to control the frequency of operation of transmitters and receivers; in radio to select one station from many; and in telephone circuits to provide communications for millions of people.

5-3. A series resonant circuit consists of inductance, capacitance, and resistance; as shown in figure 5-1. Observe that $X_L = X_C$. Draw an impedance vector diagram, and note that X_L cancels X_C. This leaves resistance as the only impedance. This is the minimum impedance possible in this series RCL circuit. Total current equals applied voltage divided by this resistance:

$$I = \frac{E_a}{Z} = \frac{10\text{ V}}{5\ \Omega} = 2\text{ amps}$$

5-4. We can list important points concerning series resonance:

a. $X_L = X_C$

b. $Z = R = \text{minimum}$

c. $I = \frac{E}{R} = \text{maximum}$

d. $E_R = E_a$

e. $E_C = E_L$

5-5. The frequency which causes the capacitive reactance and inductive reactance to be equal is the RESONANT FREQUENCY (f_r). When the resonant frequency is applied, the circuit is a RESONANT CIRCUIT. If a variable frequency power source is applied, and the frequency is varied, there will be only one frequency which causes resonance for any given series RCL circuit.

5-6. In the circuit of figure 5-2, X_L is larger than X_C. This circuit is NOT at resonance. If we decrease the applied frequency, the circuit can be brought to resonance. The circuit of figure 5-2 is ABOVE RESONANCE because the frequency must be decreased to make the values of X_C and X_L equal.

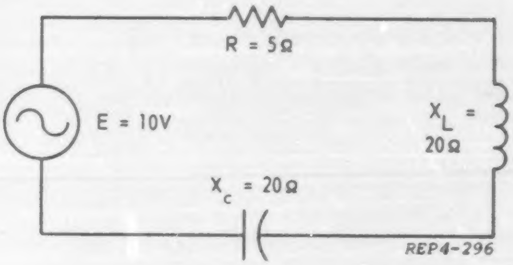


Figure 5-1. Series Resonant Circuit $X_L = X_C$

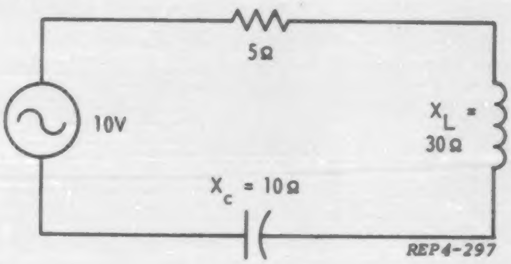


Figure 5-2

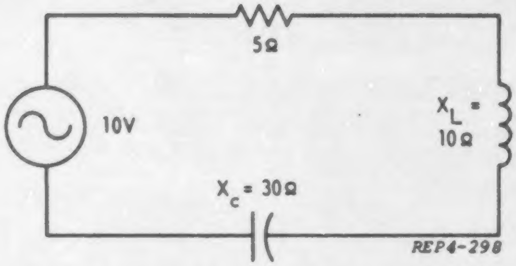


Figure 5-3

5-7. In figure 5-3, X_C is larger than X_L. This circuit is BELOW RESONANCE. The frequency must be increased to make $X_C = X_L$.

5-8. Let's compare impedance vectors for the three conditions of the above circuit (figure 5-4).

For the resonant circuit (A) the reactive values cancel leaving only resistance. The impedance angle is 0°. Recall that this is also the phase angle, and the cosine of 0° is 1. (Check this in your trigonometry tables). Thus, the power factor of a series resonant circuit is 1; PF = Cos θ. Apparent power is the true power ($P_a = P_t$).

5-9. The above-resonance impedance diagram (figure 5-4B) has a positive phase angle; the below-resonance impedance diagram (figure 5-4C) has a negative phase angle. In both of these cases the power factor is less than 1 and true power is less than apparent power.

5-10. Now, we can add more important points, concerning series resonance, to the list in paragraph 5-4.

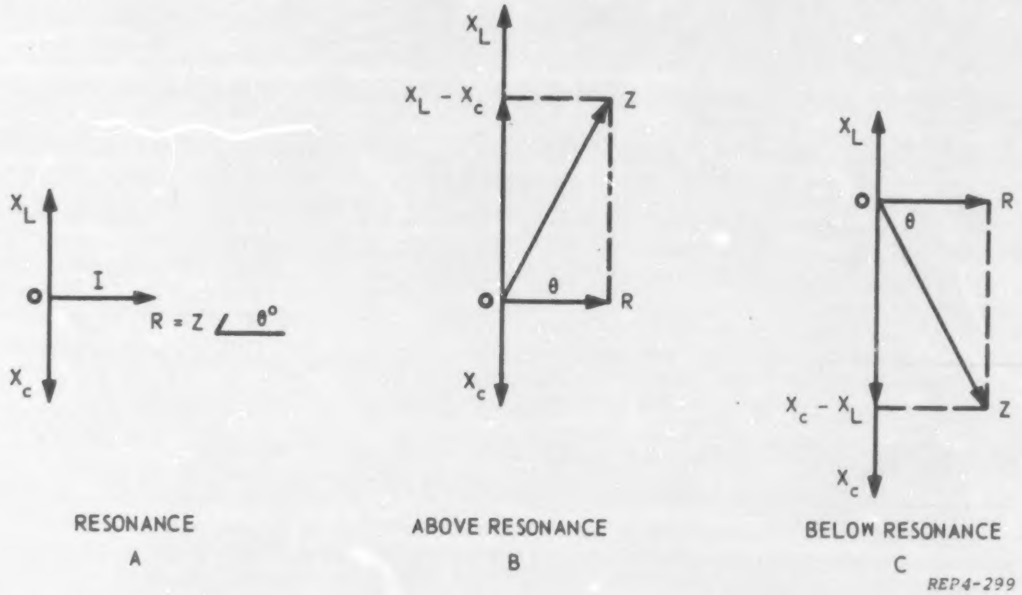
f. $\theta = 0°$

g. PF = 1

h. $P_a = P_t$

5-11. In any series RCL circuit, the only frequency at which capacitive reactance and inductive reactance are equal is the resonant frequency. To solve for the resonant frequency, use the formula

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad \text{or} \quad f_r = \frac{.159}{\sqrt{LC}}$$



RESONANCE
A

ABOVE RESONANCE
B

BELOW RESONANCE
C

Figure 5-4

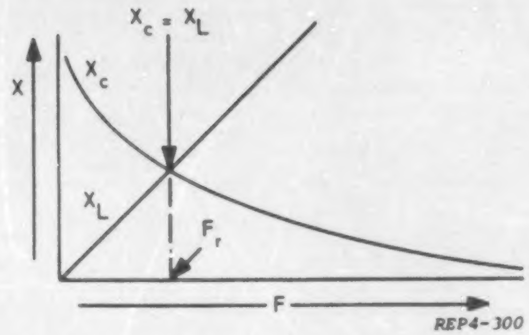


Figure 5-5

5-12. Figure 5-5 shows the relationship between X_L and X_C as frequency increases. There is a point where X_L and X_C are equal. This is the resonance point.

5-13. Refer again to figure 5-5. At 0 hertz, X_C is maximum and X_L is zero. As frequency increases toward the resonant point, X_C is larger than X_L, so the circuit is capacitive. At resonance $X_C = X_L$, so the total impedance of the circuit is resistive. As the frequency increases above resonance, X_L is larger than X_C, and the circuit is inductive. Figure 5-6 shows the resulting impedance diagram. At the resonant frequency (f_r) total impedance is resistive; impedance increases off resonance. ABOVE resonance the impedance is inductive, and BELOW resonance it is capacitive.

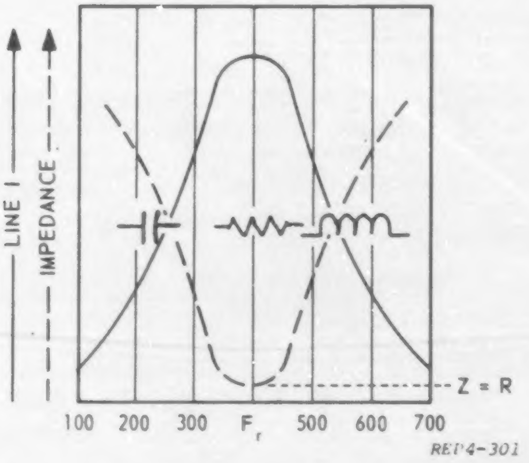


Figure 5-6

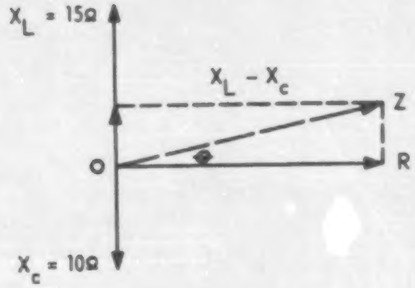


Figure 5-8

5-14. Figure 5-6 goes one step further and shows the CURRENT CURVE. At minimum impedance current is maximum.

5-15. Now, let's go back to vector analysis of series RCL circuits. At resonance, $X_L = X_C$ and the impedance of the circuit is equal to the resistance. X_L and X_C are 180° apart, they cancel out. Just resistance is left, so Z = R. Figure 5-8 shows a circuit to be inductive or ABOVE RESONANCE. X_L is larger than X_C. Figure 5-9 shows a circuit to be capacitive or BELOW RESONANCE. X_C is larger than X_L.

5-16. Deleted to include Figure 5-7.

5-17. Deleted.

5-18. ABOVE RESONANCE refers to a circuit with an applied frequency HIGHER than the resonant frequency. ABOVE RESONNANCE X_L is greater than X_C and the circuit acts inductively. By using the parallelogram method and with R as a reference, we can plot the impedance of such a circuit. Z is the vector sum of the excess X_L and the R of the circuit. (See figure 5-8).

5-19. BELOW RESONANCE refers to a circuit with a frequency LOWER than the resonant frequency. BELOW RESONANCE, X_C is greater than X_L. (See figure 5-9).

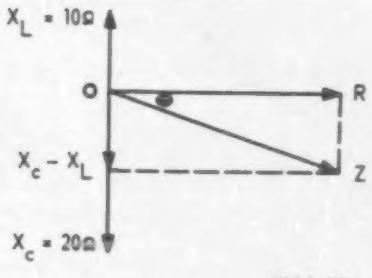


Figure 5-9

5-20. When the frequency is below the resonant frequency, the circuit acts capacitively. The opposition to the generator consists of resistance and capacitive reactance (vector sum of R and $X_C - X_L$). With an applied frequency higher than the resonant frequency, X_L is larger than X_C; now the impedance becomes the vector sum of R and $X_L - X_C$. At this time, the generator "sees" only resistance and inductive reactance. (Draw the impedance diagrams to prove this for yourself.

5-21. The impedance curve of a series RCL circuit is shown in figure 5-10, and the phase angle is 0°, X_C and X_L are equal. The only impedance at that time is the resistance of the circuit. We are then at resonance, impedance is minimum, and current is maximum.

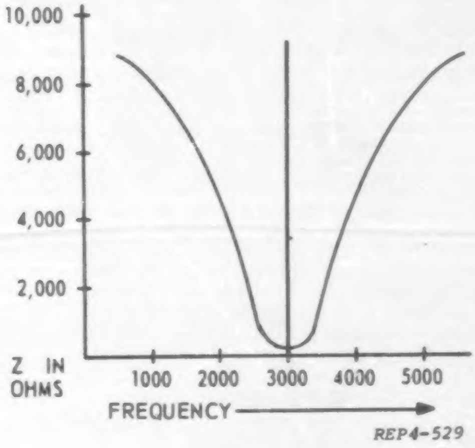


Figure 5-10

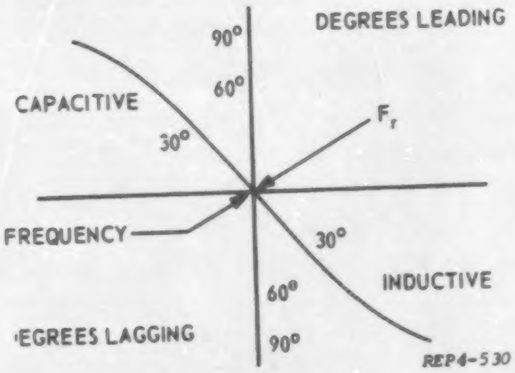


Figure 5-11

5-22. The farther you are from the resonant frequency of 3000 Hz, the higher the impedance. As you approach the resonant frequency, the impedance decreases until, at that exact point where $X_L = X_C$, the circuit is at resonance; the impedance is MINIMUM; and the current is maximum.

5-23. Now, let's consider the relationship of current and voltage in series resonant circuits.

5-24. Connect an ammeter in the circuit in figure 5-12A at points A, B, or C; the

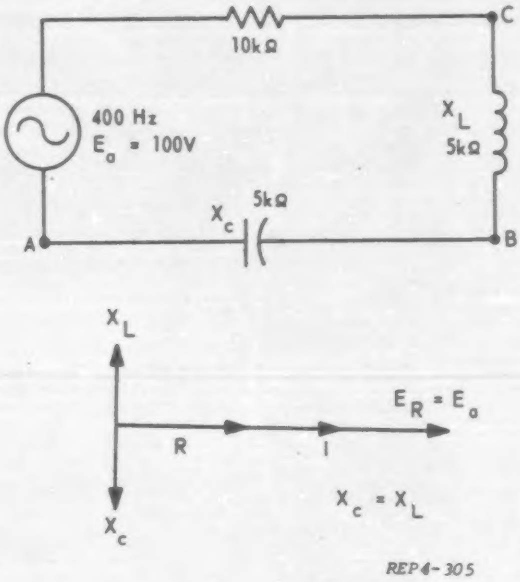
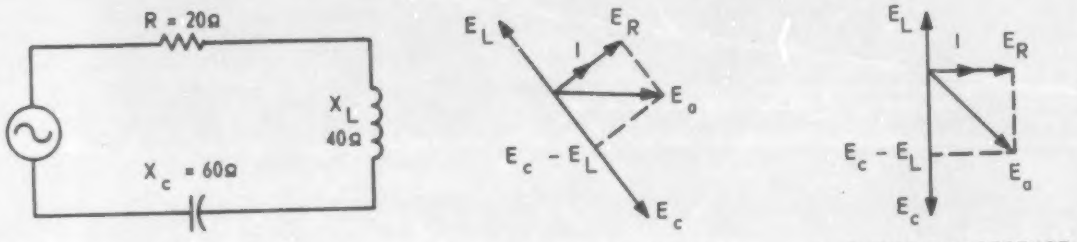


Figure 5-12



A. CIRCUIT B. VOLTAGE REFERENCE C. CURRENT REFERENCE

Figure 5-13

CURRENT indication will be the SAME. This is a series circuit with one path for current.

5-25. Deleted.

5-26. The voltage across the inductor leads the current through the inductor by 90°, and the capacitor voltage lags the capacitor current by 90°. The voltage across the resistor is in-phase with the current. When you have a resonant circuit, the capacitive and inductive reactances cancel each other; and at this time the CIRCUIT CURRENT, the RESISTOR VOLTAGE and the APPLIED VOLTAGE are all in phase.

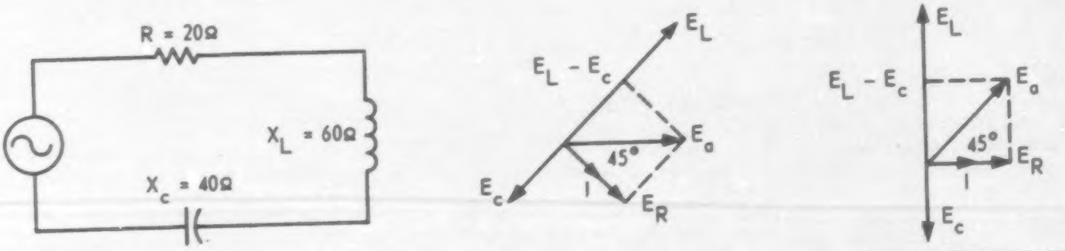
5-27. A resonant circuit is shown in figure 5-12. Reactance values cancel; Z = R, and I and E_a are in phase. The voltage drop across the resistor equals the applied voltage.

5-28. Figure 5-13A shows a circuit that is BELOW RESONANCE. Two separate vector diagrams (figure 5-13B and C) show E_a and I as references. The circuit is capacitive because current is LEADING the applied voltage. The angle is 45° because the net reactance equals the resistance.

5-29. Now, for ABOVE RESONANCE, figure 5-14A shows X_L = 60 ohms and X_C = 40 ohms. Now the vector diagrams of E_L, E_C, I, and E_R, and E_a will be as shown in figure 5-14B and C. The circuit is inductive because current LAGS the applied voltage. The angle is 45° because resistance equals the net reactance. Notice E_a and I are each used as a reference vector.

5-30. Deleted.

5-31. Refer to figure 5-15 and note the shape of the current curve of a typical series resonant circuit. From its peak at f_r, current drops off at frequencies above and below resonance. There are two points on the curve which are 70.7 percent of the peak current value. They are called HALF POWER POINTS. The frequency range between the half power points is called the BANDWIDTH (BW) of the resonant circuit.



A. CIRCUIT B. VOLTAGE REFERENCE C. CURRENT REFERENCE

Figure 5-14

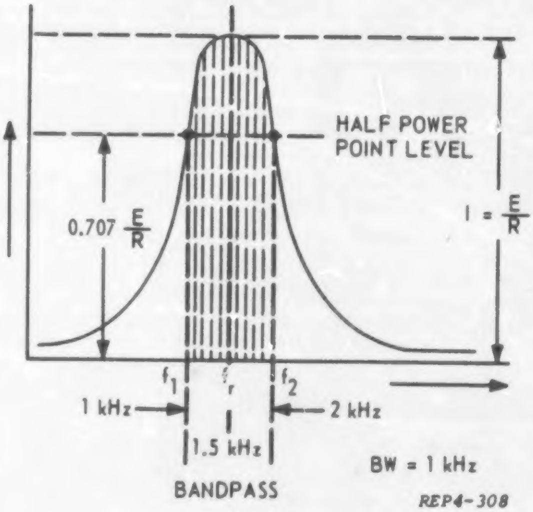


Figure 5-15

5-32. The resonant frequency in figure 5-15 is 1.5 kHz; at this point current is maximum. Current falls to .707 of its maximum value at 1 kHz on the low side and 2 kHz on the high side. To determine the bandwidth, use the formula: $BW = f_2 - f_1$. The bandwidth in this case is 1 kHz.

5-33. Figure 5-15 also shows that current drops off rapidly when the frequency applied to the circuit is below 1 kHz or above 2 kHz. Frequencies between the two half power points are in the BANDPASS REGION. The bandpass frequencies then cover 1 kHz to 2 kHz.

5-34. Increasing the resistance of a resonant circuit has no effect on the resonant frequency point. The resonant frequency formula shows this:

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{.159}{\sqrt{LC}}$$

On the other hand, current at resonance is determined by resistance only, since X_C and X_L cancel. Increasing R, then decreases resonant frequency CURRENT. It does NOT change the RESONANT FREQUENCY. Changing circuit resistance does change "circuit Q."

4-35. "Q" is defined as the ratio of energy stored (by the reactive components) to the energy dissipated (by the resistance). This ratio can be expressed as:

$$Q = \frac{P_{reactive}}{P_{true}} = \frac{I^2 X_L}{I^2 R} = \frac{X_L}{R}$$

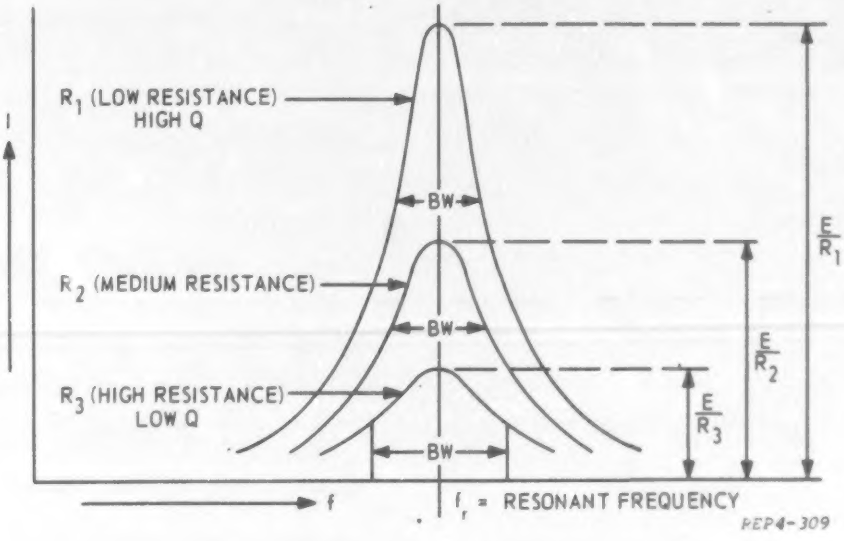


Figure 5-16

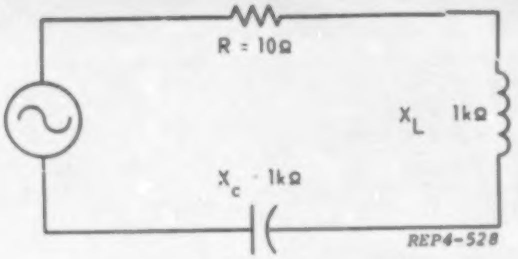


Figure 5-17

Increasing the value of series resistance, lowers the "Q" of the circuit.

5-36. "Circuit Q" applies to resonant circuits. "Circuit Q" is the ratio of X_L to the total resistance in the circuit.

5-37. Figure 5-16 shows current curves which result from changing resistance in an RCL circuit. Changing the circuit resistance from low to high changes the circuit Q from HIGH to LOW.

5-38. When the resistance is small, current at resonance is high, and the slope of the current curve is steep. A HIGH Q circuit has a rapid decrease in current as frequency is varied above and below f_r. This causes a narrow bandwidth. Only a narrow band of frequencies will be between the half power points.

5-39. A HIGH Q circuit thus has high SELECTIVITY. We define selectivity: Ability to select a narrow band of frequencies and reject all others. High Q resonant circuits are used in radio or television so you can select one broadcast station at a time.

5-40. When resistance is high in a series RCL circuit, current at resonance is low, Q is low, and the current curve shows a broad frequency response. Bandwidth is wide and circuit selectivity is poor.

5-41. Where good selectivity is required, the RCL circuit usually has no resistor component. The total resistance in the circuit is the internal resistance of the coil and the "distributed" resistance of the wiring.

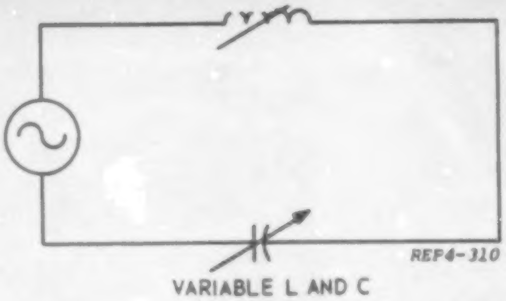


Figure 5-18

5-42. Have you noted the relationship between Q and BANDWIDTH? Examine the formula: $BW = \frac{f_r}{Q}$. A LOW Q circuit will have a larger bandwidth than a HIGH Q circuit. The LOW Q circuit will be less SELECTIVE. What about resistance? It is DIRECTLY proportional; if resistance is high, BANDWIDTH will be wide. $Q = \frac{X_L}{R}$. Increasing R will decrease Q. $BW = \frac{f_r}{Q}$. Decreasing Q causes BW to increase.

5-43. Figure 5-17 is a high Q circuit. An important property of this circuit is that its IMPEDANCE is low AT RESONANCE and increases rapidly as the frequency is changed above or below resonance. Q is the ratio of X_L over R and is considered high if it is 10 or more. $Q = \frac{X_L}{R} = \frac{1000}{10} = 100$ for this circuit.

5-44. Inductance and capacitance determine the resonant frequency of a circuit; when either one is changed, the resonant frequency changes. When you tune your radio, you are actually changing a variable capacitor; and as a result you are tuning a circuit to the frequency of the radio station you want to hear. We also have adjustable inductors. A coil may have a movable core - which can be varied to change inductance. Changing inductance will change the resonant frequency. Figure 5-18 shows a series circuit with a variable coil and a variable capacitor.

GENERATOR BELOW RESONANCE

INCREASE IN	CURRENT WILL	IMPEDANCE WILL	PHASE ANGLE WILL
FREQUENCY	↑	↓	↓
RESISTANCE	↓	↑	↓
CAPACITANCE	↑	↓	↓
INDUCTANCE	↑	↓	↓

REP4-311

Figure 5-19

GENERATOR ABOVE RESONANCE

INCREASE IN	CURRENT WILL	IMPEDANCE WILL	PHASE ANGLE WILL
FREQUENCY	↓	↑	↑
RESISTANCE	↓	↑	↓
CAPACITANCE	↓	↑	↑
INDUCTANCE	↓	↑	↑

REP4-312

Figure 5-20

5-45. In series RCL circuits if we change the frequency we change the capacitive reactance and the inductive reactance; this changes the impedance. Just what are the effects on current, impedance, and phase angle when we vary frequency, resistance, capacitance, or inductance? Perhaps a chart would be a good way to see this. In figure 5-19, the frequency of the generator is below the resonant frequency of the circuit. X_C is larger than X_L and the circuit is acting capacitively.

5-46. If you have difficulty understanding this chart, refer back to figures 5-5 and 5-6 and the formula for resonant frequency:

$$f_r = \frac{.159}{\sqrt{LC}}$$

With the generator frequency below the resonant frequency:

a. Increasing frequency approaches the resonant frequency.

b. Increasing resistance increases impedance. $Z = \sqrt{R^2 + (X_L - X_C)^2}$

c. Increasing capacitance decreases the resonant frequency, thus approaches resonance.

d. Increasing inductance decreases the resonant frequency, thus approaches resonance.

5-47. In figure 5-20 with the generator frequency above resonance, arrows indicate the result of an increase in F, R, C, and L. Increasing resistance increases impedance, makes the circuit more resistive, and decreases the phase angle. Increasing F, L, and C takes the circuit farther away from resonance, increasing impedance and the phase angle.

Chapter 6

PARALLEL RESONANT CIRCUITS

6-1. In parallel RCL circuits, resonance occurs when the frequency applied causes $I_C = I_L$. This chapter begins by solving for resonant frequency; then we discuss how parallel resonance differs from series resonance; then gives a thorough analysis of TANK circuit operation.

6-2. The first objective is to calculate the resonant frequency of a parallel RCL circuit. Use the resonant frequency formula and the values indicated in figure 6-1.

$$f_r = \frac{.159}{\sqrt{LC}}$$

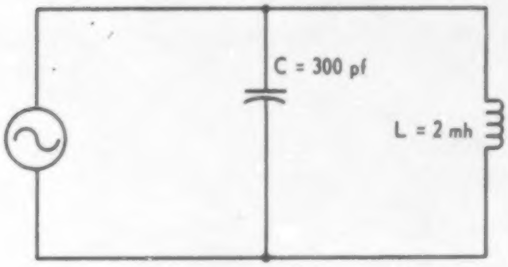


Figure 6-1

Let's go through the steps necessary to find the resonant frequency.

$$f_r = \frac{.159}{\sqrt{LC}}$$

$$= \frac{.159}{\sqrt{(2 \times 10^{-3}) \times (300 \times 10^{-12})}}$$

$$= \frac{.159}{\sqrt{600 \times 10^{-15}}}$$

$$= \frac{.159}{\sqrt{60 \times 10^{-14}}}$$

$$= \frac{.159}{7.75 \times 10^{-7}}$$

$$= \frac{.159 \times 10^{7}}{7.75}$$

$$= 205 \text{ kHz}$$

Finding the resonant frequency of a parallel RCL circuit is just a matter of using the resonant frequency formula correctly.

6-3. The voltage in the circuit of figure 6-2 is the same across each branch of the parallel RCL circuit. Further, the current in each branch is determined by the amount of resistance or the amount of reactance.

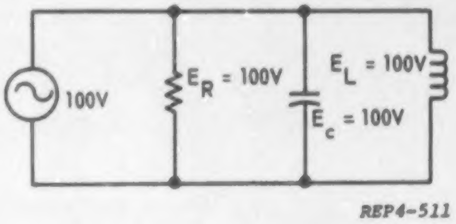
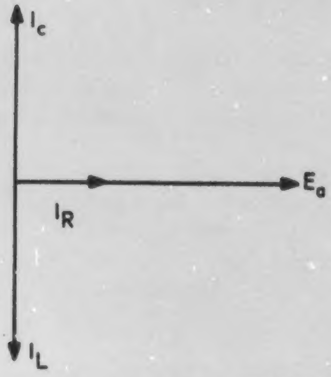


Figure 6-2

6-4. Remember this. You can NOT add these currents arithmetically; you MUST add them vectorially. The CURRENTS are NOT in phase.

6-5. Current in the resistive branch is in phase with E_a; current in the capacitive branch is leading E_a; and current in the inductive branch is lagging E_a.

6-6. Let's draw a vector diagram to see what happens. The reactances are equal and the same voltage is applied to both. The current will be equal and opposite as shown in figure 6-3. The current vectors will cancel. This leaves only the current through the resistive branch. See figure 6-3. This current value can be determined by: $I_R = \frac{E_a}{R}$ and $I_R = I_t$. Total impedance can be determined by: $Z = \frac{E_a}{I_R}$. The very small current indicates a very high impedance. I_R is in phase with E_a.



REP4-513

Figure 6-3

6-7. Let's analyze the parallel RCL circuit by changing frequency and determining its effect on current flow.

6-8. Since changing frequency has no effect on the amount of current that will flow in the resistive branch, we will disregard this branch for now.

6-9. Recalling the formulas $X_L = 2\pi fL$ and $X_C = \frac{1}{2\pi fC}$ it is apparent that X_L increases with frequency and X_C decreases. Therefore, as frequency increases above resonance, capacitive current becomes greater than the inductive current and I_{line} increases (see figure 6-4). As the frequency is decreased below resonance I_L is more than I_C and I_{line} increases (figure 6-5). The currents change because $I_L = \frac{E_a}{X_L}$; $I_C = \frac{E_a}{X_C}$; and $(I_{line})^2 = (I_R)^2 + (I_L - I_C)^2$.

6-10. Parallel resonant circuits present a high opposition to the voltage force of the generator. Let's examine the action of an LC tank at resonance by placing a charge across the capacitor as shown in figure 6-6.

6-11. Moving the switch to the right completes the circuit from the capacitor to the inductor. It places the inductor in series with the capacitor. This furnishes a path for electron flow from the upper plate of the capacitor to the lower plate to neutralize the capacitor charge. (See figure 6-7.). As current flows through the coil, a magnetic field is built up around the coil. The energy which was stored by the electrostatic field of the capacitor is now stored in the

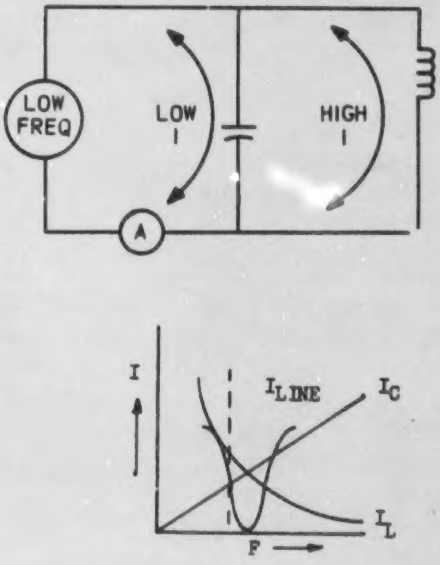


Figure 6-4

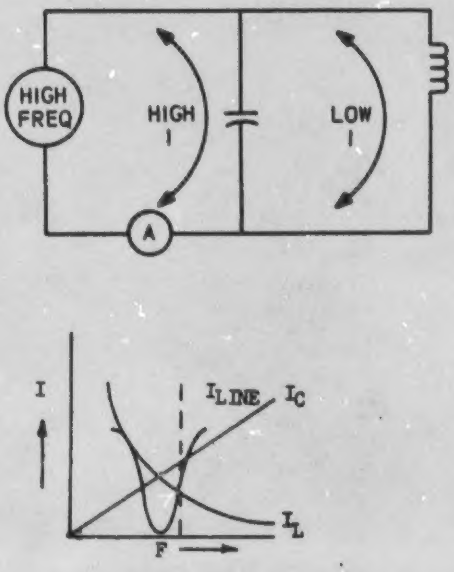
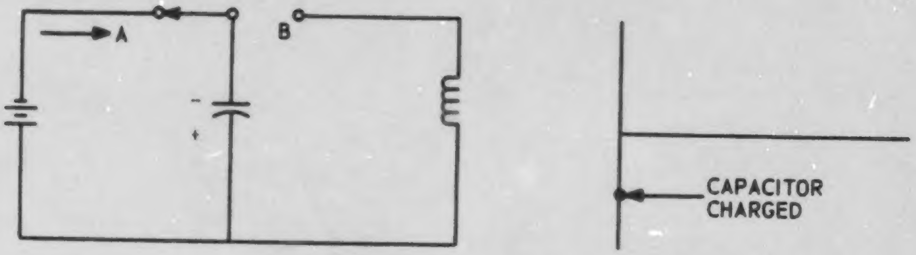


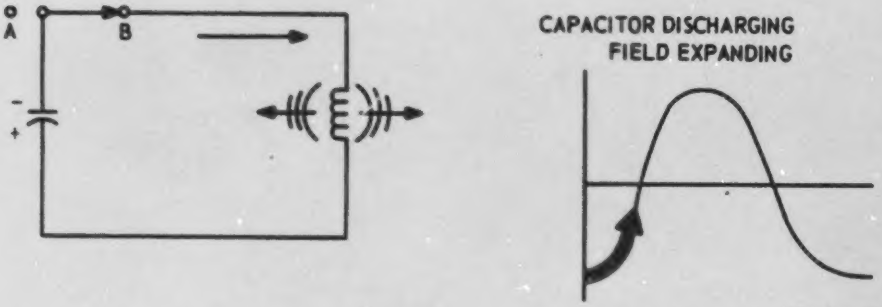
Figure 6-5

90


A
B
-
+
CAPACITOR
CHARGED

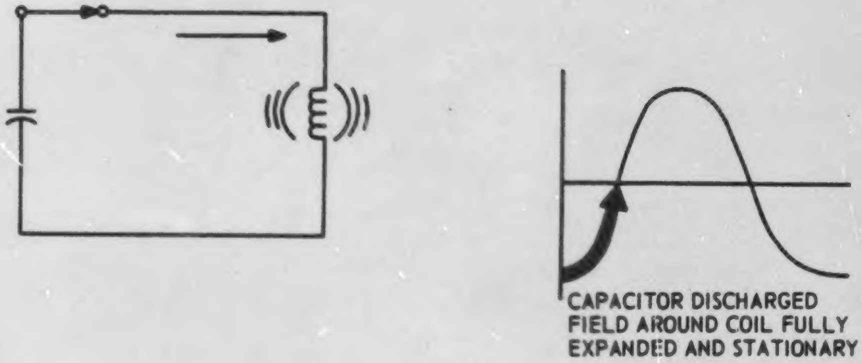
REP4-514

Figure 6-6


A
B
-
+
CAPACITOR DISCHARGING
FIELD EXPANDING

REP4-617

Figure 6-7

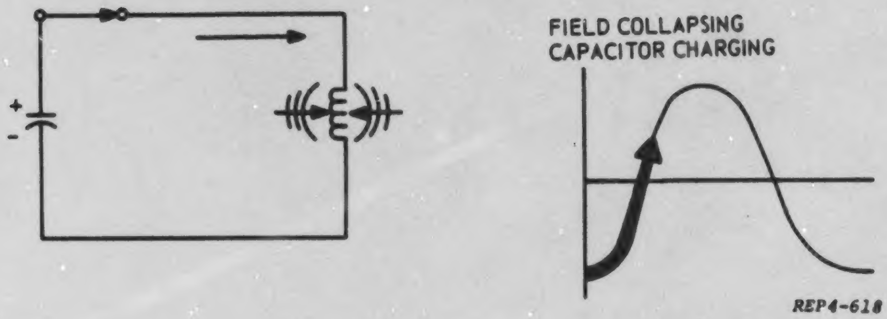

CAPACITOR DISCHARGED
FIELD AROUND COIL FULLY
EXPANDED AND STATIONARY

REP4-520

Figure 6-8

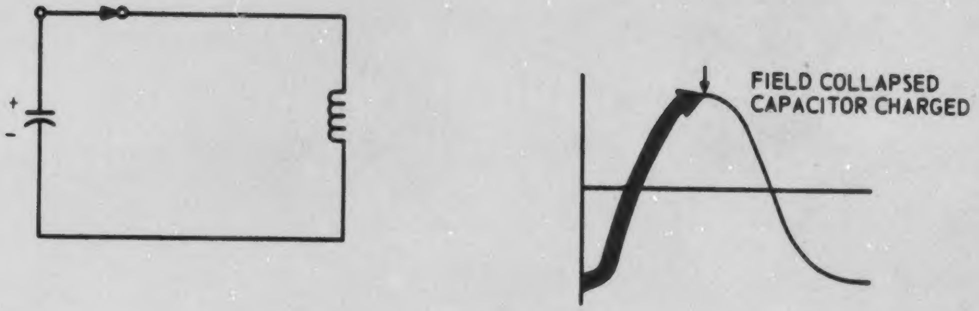
electromagnetic field of the inductor. The waveforms in figure 6-6 through 6-14 show the capacitor voltage.

6-12. Figure 6-8 shows the capacitor discharged and a maximum magnetic field around the coil.


FIELD COLLAPSING
CAPACITOR CHARGING
+
-

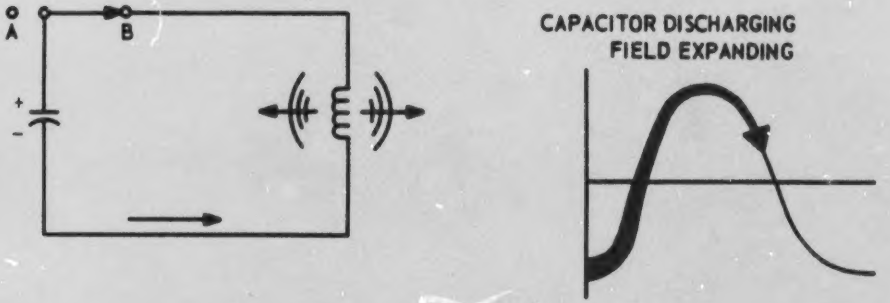
REP4-618

Figure 6-9


FIELD COLLAPSED
CAPACITOR CHARGED
+
-

REP4-521

Figure 6-10


A
B
CAPACITOR DISCHARGING
FIELD EXPANDING
+
-

REP4-619

Figure 6-11

6-13. Since the capacitor is now completely discharged, the magnetic field starts to collapse. (See figure 6-9).

6-14. This induces a voltage in the coil which causes the current to continue flowing, charging the capacitor again.

6-15. When the magnetic field has completely collapsed, the capacitor has become charged with the opposite polarity. (See figure 6-10).

6-16. If the circuit had no resistance, the amount of this reverse charge would be the same as the original charge. However, the coil and the connecting wires have some resistance; a small amount of energy is dissipated in the form of heat (I^2R loss). Therefore, the charge shown in figure 6-10 is slightly less than the original charge.

6-17. The capacitor now discharges back through the coil. This discharge current causes the magnetic field to build up around the coil. (See figure 6-11.)

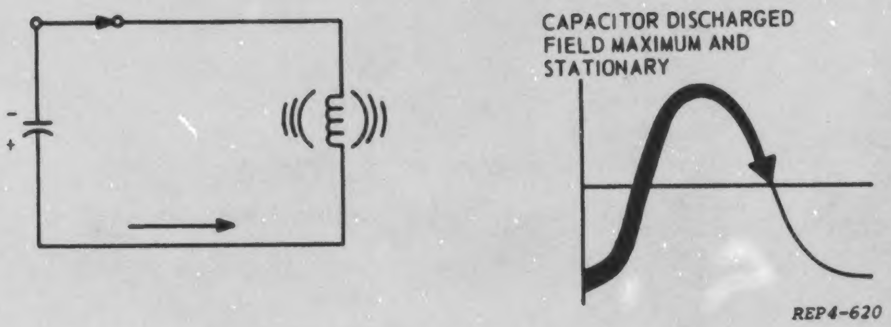

CAPACITOR DISCHARGED
FIELD MAXIMUM AND
STATIONARY
-
+
REP4-620

Figure 6-12

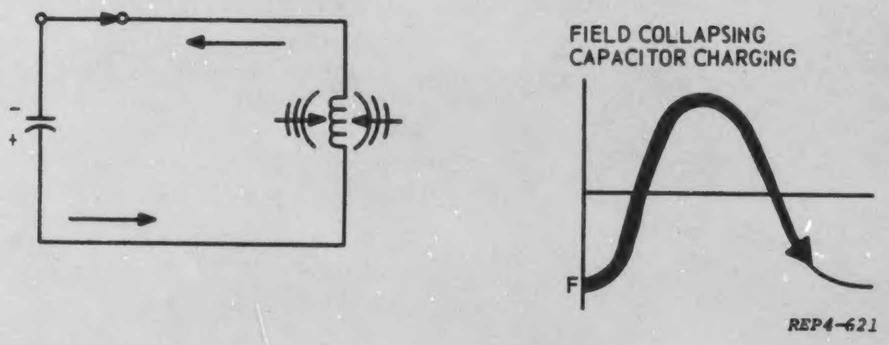

FIELD COLLAPSING
CAPACITOR CHARGING
-
+
F
REP4-621

Figure 6-13

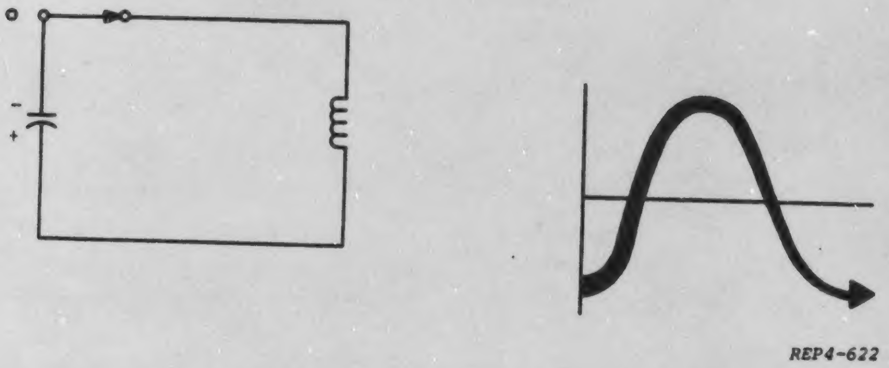


Figure 6-14

6-18. When the capacitor is completely discharged, the magnetic field is again at maximum (see figure 6-12).

6-19. The magnetic field again starts collapsing, causing the electron flow to continue toward the upper plate of the capacitor. (See figure 6-13).

6-20. By the time the magnetic field has completely collapsed, the capacitor is again charged with the same polarity as it had in figure 6-6. Compare with figure 6-14.

6-21. As the stored energy moved from the coil to the capacitor, the circuit resistance dissipated some energy in the form of heat

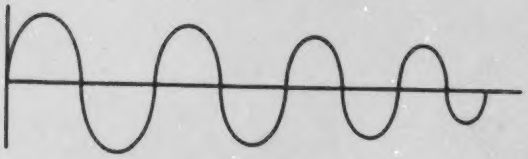


Figure 6-15

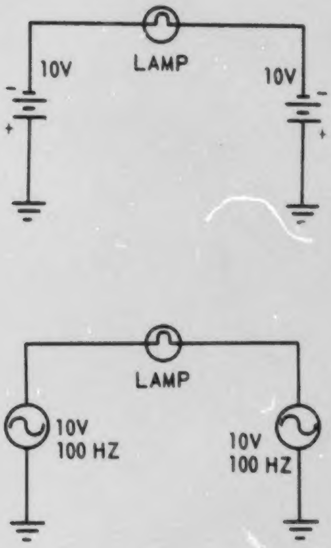


Figure 6-16. Dampened Wave

so that the charge is less than in figure 6-10.

6-22. If the circuit is not opened, the discharging and charging action will continue until all the energy has been dissipated as heat.

6-23. The number of times this set of events occurs per second is called the natural frequency (or resonant frequency) of the circuit.

6-24. In practical circuits, the heat loss in the resistance of the circuit causes each cycle to be smaller than the previous cycle. The result is a DAMPENED wave as shown in figure 6-15.

6-25. We said earlier that the opposing force of the tank could minimize line current. For current to flow, a difference in potential must exist. Picture two generators or two batteries with a lamp connected between them as in figure 6-16. In the battery circuit, it is easy to see that no current can flow through the lamp. No difference in potential exists. Likewise, if two generators are at exactly the same frequency and their outputs identical, no differences in potential can exist, and NO CURRENT CAN FLOW.

6-26. When a tank circuit is functioning at resonance , the same condition exists. See figure 6-17. You will notice by examining figure 6-17, that at any instant along the EMF sine waves, the voltage of the generator is almost counteracted by the voltage of the tank. The amplitude of the tank voltage will be slightly less than that of the generator. For this reason, a minimum current will flow in the line to replace the energy lost through I^2R.

6-27. At resonance, the parallel tank offers maximum opposition to line current. Therefore, at resonance, the parallel tank offers MAXIMUM IMPEDANCE to line current.

6-28. Recall that as frequency goes below resonance, capacitive reactance goes up and inductive reactance goes down, similarly, as frequency goes above resonance, X_C goes down and X_L goes up.

6-29. With this in mind, you can see what will happen to current flow in a parallel RCL circuit. If the frequency is very low, X_L is low and X_C is high, so more current will flow through the inductive branch. The circuit is then acting INDUCTIVELY.

6-30. Refer to figure 6-18. With $E_a = 100V$ and $X_L = 50$ ohms, $I_L = 2$ amps. With $X_C = 10$ k ohms, $I_C = .01$ amp and is negligible when compared with inductive current. This circuit is acting INDUCTIVELY.

6-31. Refer to figure 6-19. With the frequency high, the reactance values are reversed. X_C now offers 50 ohms of opposition, while X_L is 10 k ohms. Most of the

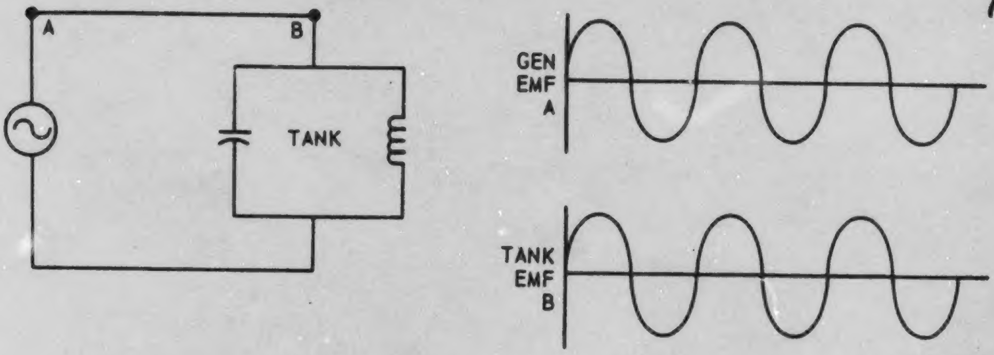


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Figure 6-17

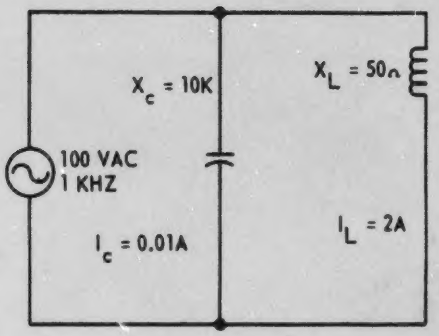

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Figure 6-18. Effect of Very Low F

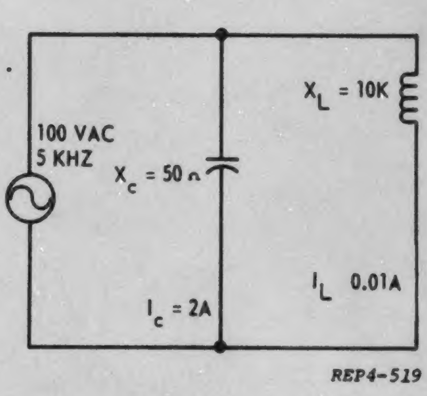

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Figure 6-19. Effect of a Very High F

current is through the capacitor. Therefore, the circuit is acting CAPACITIVELY.

6-32. With the resonant frequency applied, the tank circuit offers a very high impedance to the generator; therefore, line current decreases to a minimum.

6-33. Keep in mind that with the parallel resonant circuit, the capacitive current leads the applied voltage by 90°; and the inductive current lags the applied voltage by 90°. These two currents are equal and opposite. When the capacitor is discharging, the discharge current flows through the inductor. This stores energy in the electromagnetic field. When the magnetic field of the coil is collapsing, the resulting current flows into the capacitor. This stores energy in the electrostatic field.

6-34. The tank circuit has a small amount of resistance: the wire, internal resistance of the coil, and connections. This resistance dissipates energy as heat (I^2R loss); so a small amount of line current is permitted to flow. Since the line current is minimum at resonance, the impedance is maximum. This result can be seen from Ohm's Law:

$$Z = \frac{E}{I}$$

Chapter 7

SERIES AND PARALLEL RESONANT CIRCUITS

7-1. In this chapter, we will first compare the characteristics of series and parallel resonant circuits. Then, we will differentiate between current curves for series and for parallel RCL circuits. We will also solve for the Q of a circuit; when given the component and frequency values. Finally, we will use a tuned frequency response curve to determine the bandpass and the bandwidth of resonant circuits.

7-2. It is important that the relationship between series and parallel RCL circuits be kept in mind; so we'll look at the chart below showing the characteristics of series and parallel resonances.

7-3. You know that figure 7-1 is a parallel RCL circuit; when I_L is equal to I_C, minimum line current will flow; and the tank circuit will offer a high impedance to line current.

7-4. The object of this is not to repeat something you already know but to stress these important facts; to enable you to differentiate between an impedance curve for a series RCL circuit, and an impedance curve for a parallel RCL circuit.

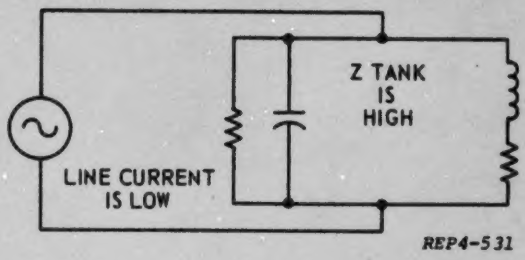

Figure 7-1

SERIES RESONANCE	PARALLEL RESONANCE
$F_r = \frac{.159}{\sqrt{LC}}$	$F_r = \frac{.159}{\sqrt{LC}}$
$X_L = X_c$	$I_L = I_C$
PF = 1	PF = 1
Z is minimum	Z is maximum
I is maximum (line)	I is minimum (line)
Bandwidth depends on Q	Bandwidth depends on Q

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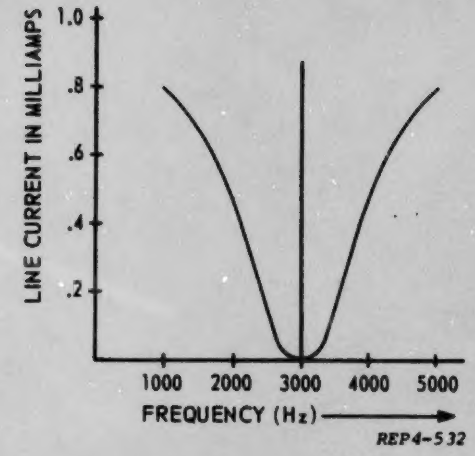

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Figure 7-2

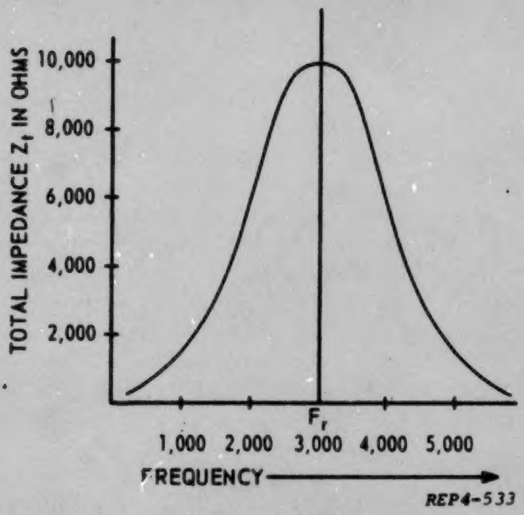

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Figure 7-3

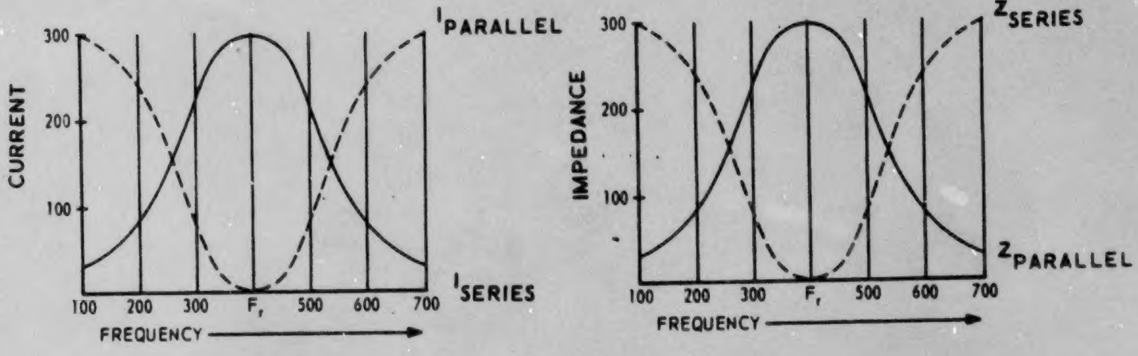
7-5. To understand the impedance curve for a parallel RCL circuit, remember that line current is minimum and Z is maximum at resonance. Figures 7-2 and 7-3 show these facts.

7-6. Just one more point regarding parallel RCL circuits at resonance: the tank circuit, due to the action of the capacitor and inductor in parallel, acts in opposition to the generator (AC) force. This means a high impedance, which, in turn, gives a low line current.

7-7. By now you should have no difficulty in differentiating between current curves for series and parallel RCL circuits. In a series RCL circuit at resonance, the impedance is minimum and the current is maximum. In a parallel RCL circuit at resonance, the impedance is maximum and the current is minimum. In figure 7-4A, the solid line curve represents current in a series RCL circuit, and the broken line is current in a parallel RCL circuit.

7-8. Figure 7-4B can be used to show impedance for a parallel or series RCL circuit. The solid line represents the impedance for a parallel circuit. The broken line represents impedance for a series circuit.

7-9. Next, we will use a two branch RCL circuit with component and frequency values



A

B

Figure 7-4

given, to determine the Q of the tank circuit. Q is defined for the circuit in figure 7-5, as the ratio of the inductive reactance to the tank circuit series resistance. A high Q circuit is highly responsive to frequency changes. In order to find Q, we use the formula:

$$Q = \frac{X_L}{R} \text{ (series resistance)}$$

R is any resistance in series with the coil.

7-10. When the series resistance of the RCL circuit is quite small, the Q will be large. Let's find the Q of the tank in figure 7-5. It is a simple matter to substitute the values of X_L and R in the formula:

$$Q = \frac{X_L \text{ (1000 ohms)}}{R \text{ (100 ohms)}} = 10$$

A Q of 10 or more is considered a high Q.

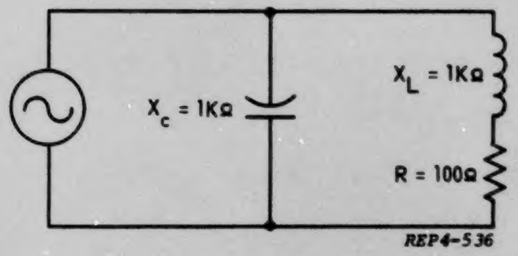


Figure 7-5

7-11. When we apply the formula for Q, you can see that the lower the resistance, the higher the Q. Inversely, if resistance is high, the Q will be low (see figure 7-6). An important point to realize is that as Q decreases, the sharpness of the curve decreases; and as Q decreases, the angle of lead or lag decreases for any one frequency except that of resonance.

7-12. The circuit of figure 7-7 shows a resistor in series with the AC generator. By examination of the circuit, you can see that it is now a series-parallel circuit. It is also evident that the voltage across the parallel branch no longer equals the applied voltage but rather $E_R + E_{tank} = E_a$.

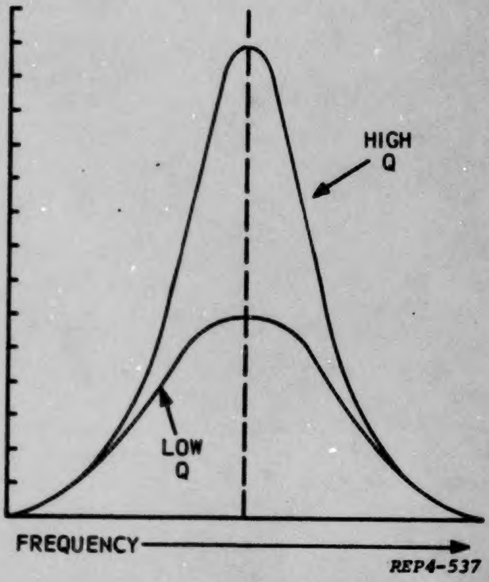


Figure 7-6

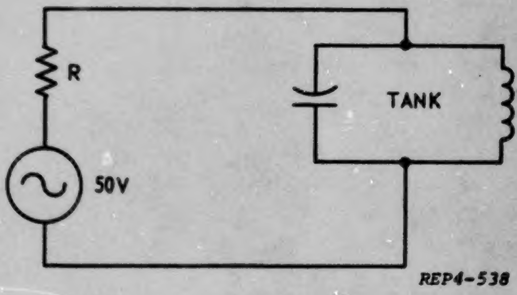


Figure 7-7

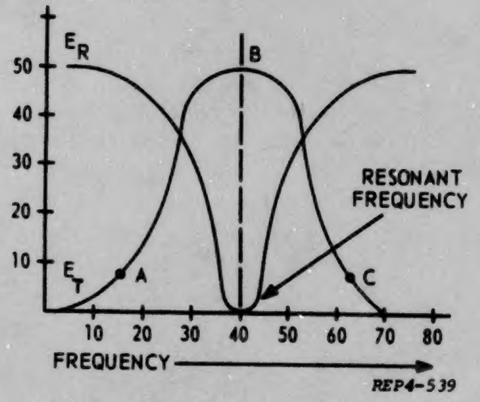


Figure 7-8

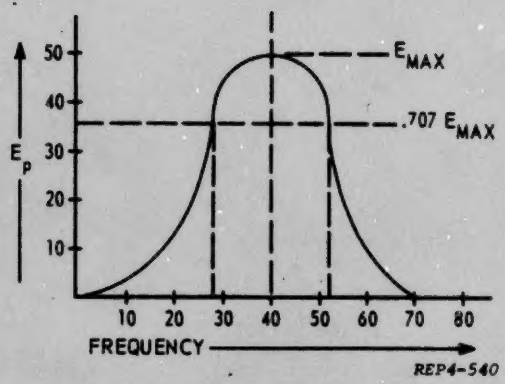


Figure 7-9

7-13. When the input frequency is varied from below resonance to above resonance, a voltage curve for the parallel tank can be drawn (see figure 7-8).

7-14. Assume the generator output is 50 V in amplitude, and its frequency may be varied from 0 to 80 Hz. Below resonance, I_C is less than I_L; and we could draw an equivalent series circuit of a resistor and a coil. Above resonance, I_L is less than I_C. Now our equivalent series circuit would have a resistor and capacitor.

7-15. You can plot the voltage curves shown in figure 7-8 if you keep in mind that E_T and E_R add vectorially and their sum is 50 volts. At resonance, point B, the reactive components cancel, so you can add the voltages directly. At 40 Hz, the drop across E_R is minimum.

7-16. The voltage response curve plotted in figure 7-8 can be used to determine BANDWIDTH and BANDPASS between the half power points. The half power points are defined as .707 x E_{max} or .707 x 50 V = 35.35 V. Mark the two 35.35 volt points on the E_T curve (see figure 7-9), and then drop lines straight down to intersect the frequency line.

7-17. To determine BANDWIDTH, find the frequency at these two points and subtract the lower from the higher (52 - 28 = 24). The BANDWIDTH under these assumed conditions is 24 Hz. BANDPASS is defined as those FREQUENCIES which cause a voltage across the parallel circuit of .707 x E_{max} (35.35 V) or more. In this case the bandpass is from 28 to 52 Hz.

7-18. An impedance curve may also be used to determine bandwidth and bandpass. See figure 7-10.

7-19. In this method, we take .707 times Z MAXIMUM to establish a line through the curve at points A and B. By dropping lines down from these points to the frequency reference line, we can determine the bandpass to be from 1200 Hz to 2200 Hz. The bandwidth would be the difference between 1200 and 2200 Hz or 1000 Hz.

7-20. The 3-branch parallel resonant circuit differs from the 2-branch in the number of

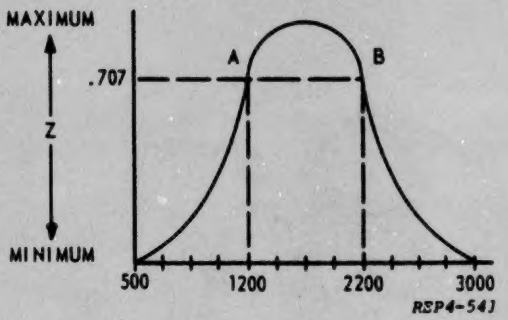


Figure 7-10

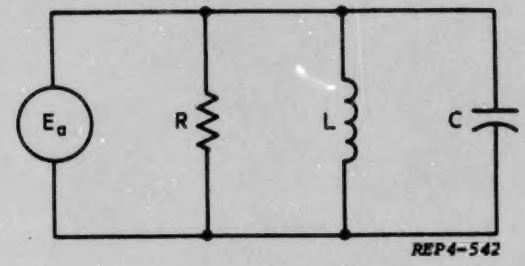


Figure 7-11

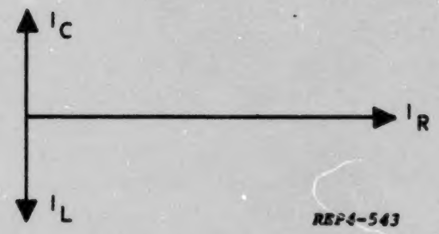


Figure 7-12

possible current paths. A 3-branch circuit configuration is shown in figure 7-11. The combination of L and C in figure 7-11 form a parallel resonant circuit. Notice that there is no resistance shown in series with the inductive branch. At resonance, the vector diagram of the branch currents will be as shown in figure 7-12.

7-21. If the reactive currents (I_C and I_L) are equal, the circuit will appear to be a purely resistive circuit. It will have an impedance value that is equal to R. The circuit shown in figure 7-13 may be solved for its currents, impedance, circuit Q and other characteristics in the following manner:

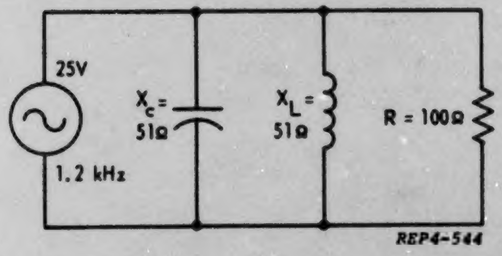


Figure 7-13

Given

$E_a = 25$ V

$X_C = 51$ ohms

$X_L = 51$ ohms

F = 1.2 kHz

R = 100 ohms

Find

$I_C =$

$I_L =$

Q =

$I_{tank} =$

$I_{line} =$

Solution

Determine I_C:

$$I_C = \frac{E_a}{X_C} \quad \frac{25 \text{ V } \angle 0^\circ}{51\Omega \angle -90^\circ} = 490 \text{ mA } \angle 90^\circ$$

Determine I_L:

$$I_L = \frac{E_a}{X_L} = \frac{25 \text{ V } \angle 0^\circ}{51\Omega \angle 90^\circ} = 490 \text{ mA } \angle 90^\circ$$

Determine I_R:

$$I_R = \frac{E_a}{R} = \frac{25 \text{ V } \angle 0^\circ}{100\Omega \angle 0^\circ} = 250 \text{ mA } \angle 0^\circ$$

7-22. To determine the current drawn from the source (line current), insure all currents

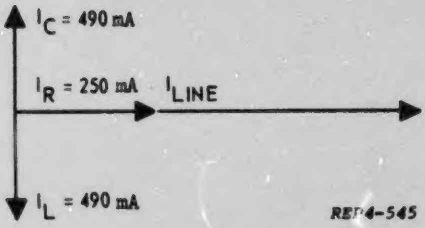


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Figure 7-14

are in vector form and add, as in figure 7-14. Since the reactive currents cancel, the line current is equal to the current drawn by the resistive component. At resonance:

$$I_{line} = I_R$$

7-23. Since the circulating current of the resonant tank is the same for either reactive component; then tank current may be found by determining current flow through the capacitor or inductor.

$$I_{tank} = \frac{E_a}{X_C} = \frac{25\text{ V}}{51\,\Omega} = 490\text{ mA}$$

At resonance:

$$I_{tank} = I_C = I_L$$

7-24. The LC combination in figure 7-13 forms an ideal parallel resonant network. The impedance of the tank circuit under these conditions may be considered to be infinite. The equivalent resistance offered to the source by the parallel circuit composed of an infinite impedance in parallel with a resistance is equal to the value of the resistance. The circuit impedance can be determined in the following manner:

$$Z = \frac{E_a}{I_{line}} = \frac{25\text{ V}}{0.25\text{ A}} = 100\text{ ohms}$$

To determine the value of Q for figure 7-13 use the formula:

$$Q = \frac{I_{tank}}{I_{line}} = \frac{490\text{ mA}}{250\text{ mA}} = 1.96$$

or:

$$Q = \frac{R}{X_L} = \frac{100\,\Omega}{51\,\Omega} = 1.96$$

7-25. Notice that the formula $Q = \frac{R}{X_L}$ is just opposite of the formula used in the 2-branch parallel resonant circuit of figure 7-5.

7-26. The 3-branch RCL circuits have the terms bandwidth and selectivity applied to them. The formula for bandwidth undergoes slight modification; i.e., it will not be the same as for the 2-branch circuit. In the 3-branch circuits parallel resonant circuit bandwidth equals $BW = \frac{f_r \times X_L}{R}$.

7-27. If the parallel resistance is increased, the line current goes down. As the shunting resistance approaches infinity, the line current approaches zero. As resistance is increased, the bandwidth becomes narrower, and the selectivity increases. Therefore, it can be seen how regulation of the bandwidth may be accomplished by variation of the shunt, or "swamping" resistor. The inverse relationship between resistance and bandwidth may be seen by examination of equations above and the curves in figure 7-15.

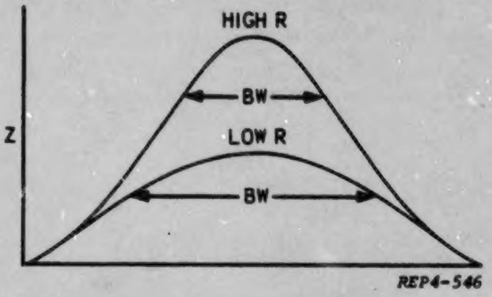

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Figure 7-15

Chapter 8

PARAMETER CHANGES IN PARALLEL RESONANT CIRCUITS

8-1. In this section of the text you will study the effects of increasing the applied frequency, resistance, capacitance, or inductance in a parallel circuit. We will change only one of these factors at a time and use charts and vectors to show the effects of these changes.

8-2. At Resonance

8-3. At resonance the inductive reactance (X_L) and the capacitive reactance (X_C) are equal and therefore cancel each other. The current in the CAPACITIVE branch is equal to:

$$I_C = \frac{E_a}{X_C}$$

Likewise, the INDUCTIVE branch:

$$I_L = \frac{E_a}{X_L}$$

8-4. Currents in both branches are equal and are shown as vectors in figure 8-1A. The current flow through the resistor is the total current (I_t) in the circuit. Because I_L and I_C are 180 degrees out of phase and equal in value, they cancel and do not flow through the resistor.

8-5. At resonance the resistor current and total current are one and the same. There will be NO phase angle difference – the phase angle is zero. Remember, this is when the circuit is at resonance.

8-6. Now, let us INCREASE frequency, keeping in mind the formulas:

$$X_L = 2\pi fL \text{ and } I_L = \frac{E_a}{X_L}$$

$$X_C = \frac{1}{2\pi fC} \text{ and } I_C = \frac{E_a}{X_C}$$

As frequency goes higher, X_C has to DECREASE; this means that I_C will INCREASE. Also as frequency goes higher, X_L has to INCREASE and I_L will DECREASE. There will be less I_L to subtract from I_C, and I_t will INCREASE. $I_t^2 = I_R^2 + (I_C - I_L)^2$. The vector diagram in figure 8-1B illustrates these facts and Table 8-1 shows the results. Since it is evident that current has increased, what must have happened to impedance? The total OPPOSITION to current has DECREASED. $Z = \frac{E_a}{I_t}$. Again, referring to the vector diagram of figure 8-1B, notice that total current is NOT in phase with the resistor current. Total current is leading the resistor current by some angle. The phase angle has increased from zero. As the angle increases, the cosine (power factor) decreases.

8-7. Now, assume that resistance increases and find out what effect this has on current.

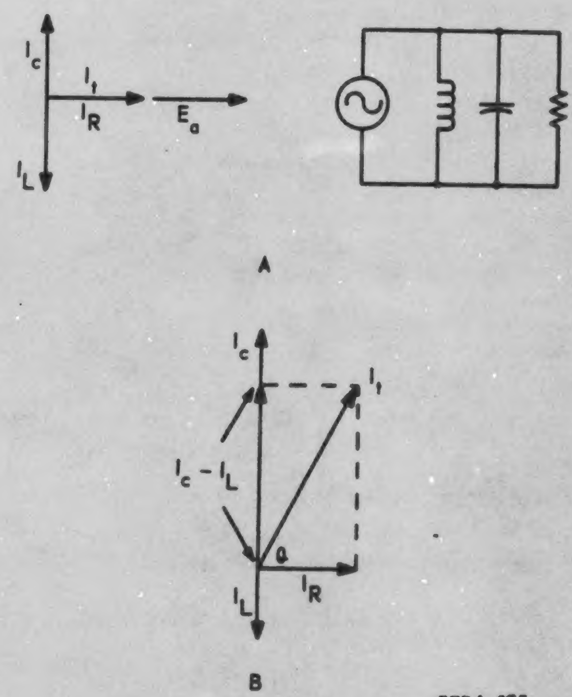

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Figure 8-1

Table 8-1

STARTING AT RESONANCE

Increase In	Current Will	Impedance Will	Phase Angle Will
Frequency	Increase	Decrease	Increase
Resistance	Decrease	Increase	Not Change
Capacitance	Increase	Decrease	Increase
Inductance	Increase	Decrease	Increase

Remember that: $I_R = \frac{E_a}{R}$ and at resonance $I_R = I_t$. Now you can see that an INCREASE in resistance INCREASES impedance, which in turn DECREASES current flow. At resonance the phase angle does not change because I_L and I_C have not changed.

8-8. Now increase capacitance. To determine the results remember that:

$$X_C = \frac{1}{2\pi fC} \quad \text{and} \quad I_C = \frac{E_a}{X_C}$$

8-9. When there is an INCREASE in C, we have a DECREASE in X_C. This causes an INCREASE in I_C. Because I_L no longer cancels I_C, there is an INCREASE in I_t. See figure 8-1B. What happens to phase angle? It increases the same as it did when we increased frequency.

8-10. When inductance INCREASES, the inductive reactance INCREASES, because $X_L = 2\pi fL$. When this happens, I_L DECREASES and no longer cancels I_C. Total current INCREASES and impedance DECREASES. As the inductance is INCREASED, the phase angle will INCREASE.

8-11. We have now analyzed the effects of an increase in frequency, resistance, capacitance, and inductance starting AT RESONANCE in a parallel RCL circuit.

8-12. Below Resonance

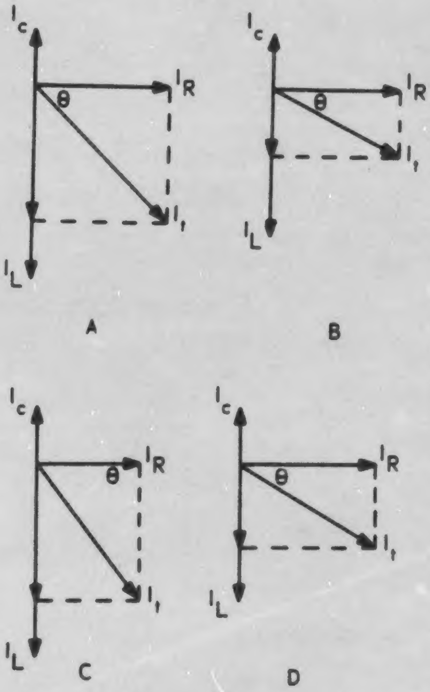

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Figure 8-2

8-13. Notice that BELOW RESONANCE X_L is smaller than X_C. Because X_L is smaller, the vector for I_L is larger than the vector for I_C. See figure 8-2A. Note that I_t lags I_R and the circuit acts inductively.

8-14. If we were to increase frequency, then X_L increases and X_C would decrease. Therefore, I_L would decrease and I_C will increase.

Table 8-2

STARTING BELOW RESONANCE

Increase In	Current Will	Impedance Will	Phase Angle Will
Frequency	Decrease	Increase	Decrease
Resistance	Decrease	Increase	Increase
Capacitance	Decrease	Increase	Decrease
Inductance	Decrease	Increase	Decrease

As the frequency approaches resonance the increase in I_C will cancel more of I_L and I_t will decrease. See figure 8-2B. The phase angle has become less because the total reactive current has decreased (I_L-I_C). The I_t vector has moved closer to the applied voltage vector.

8-15. Now increase resistance while operating below resonance. The decrease in I_R when combined with the reactive current will decrease total current. See figure 8-2C. Impedance must have increased ($Z = \frac{E_a}{I_t}$). With the increase in resistance, the I_t vector will move closer to the reactive vector and the phase angle will INCREASE.

8-16. What happens when we increase capacitance while operating below resonance? The formula for capacitive reactance just about answers our question – let's look at it:

$$X_C = \frac{1}{2\pi fC}$$

When C goes up, X_C goes down. When X_C goes down, there is less opposition to current flow and I_C goes up. Remember we have not changed frequency, so I_L will not change. Now I_C will cancel more of I_L and the reactive current will decrease. When you combine the I_R with the difference in the reactive current, you find that I_t has decreased. $I_t^2 = I_R^2 + (I_L - I_C)^2$. A decrease in I_t means that impedance has increased. The I_t vector has moved closer to the E_a vector. The phase angle has decreased.

8-17. The last one is an increase of inductance. $X_L = 2\pi fL$. As L goes up, X_L has to go up, and I_L has to decrease. Impedance is increasing, and I_t is decreasing, and moving closer to E_a; therefore, the phase angle is decreasing. See figure 8-2D.

8-18. Table 8-2 summarizes the changes that occur for increases in frequency, resistance, capacitance, and inductance in a circuit that is operating below resonance.

8-19. Above Resonance

8-20. The last table we will discuss starts at an ABOVE RESONANCE condition. We will go through the same procedure to determine the effects of an INCREASE in frequency, resistance, inductance, or capacitance. Refer to figure 8-3.

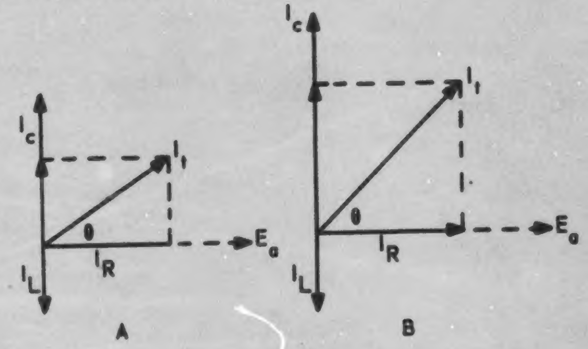

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Figure 8-3

8-21. Above resonance simply means that I_C is greater than I_L. Again the capacitive reactance formula and the inductive reactance formulas must be kept in mind:

$$X_C = \frac{1}{2\pi fC} \text{ and } I_C = \frac{E_a}{X_C}$$

$$X_L = 2\pi fL \text{ and } I_L = \frac{E_a}{X_L}$$

8-22. If you have an increase in frequency, X_C will decrease and X_L will increase; I_C will increase and I_L will decrease. The difference between I_C and I_L will increase and when combined with I_R will increase total current. When there is an increase in total current, the impedance must have decreased. When I_C increases the I_t vector will move closer to the I_C vector. When this happens, the phase angle increases.

8-23. With an increase in resistance, we have a decrease in total current and an increase in impedance.

8-24. When we start above resonance and increase capacitance, we again apply the formulas:

$$X_C = \frac{1}{2\pi fC} \text{ and } I_C = \frac{E_a}{X_C}$$

As capacitance goes up, X_C decreases and I_C increases. An increase in I_C will increase I_t. As this takes place, the phase angle is increasing. To sum up what happens when the capacitance is increased: total current increased, impedance decreased, and phase angle increased.

8-25. When there is an increase in inductance while above resonance, you can see by the formula $X_L = 2\pi fL$ that the inductive reactance has to increase. This causes the inductive current to decrease. I_L will cancel less of I_C and increases total reactive current. $I_t^2 = I_R^2 + (I_L - I_C)^2$. This being the case, the total impedance must have decreased. $Z = \frac{E_a}{I_t}$. The I_t vector moves closer to the I_C vector and the phase angle increases. $\frac{I_C}{I_t} = \text{Sin} \underline{/\theta}$

8-26. Table 8-3 summarizes the changes that occur for increases in frequency, resistance, capacitance, and inductance in a circuit that is operating above resonance.

8-27. This lesson combines several facts that you already know. For example, the fact that when opposition to current flow becomes less, then current must increase; or, when current increases, impedance must have decreased (providing voltage remains the same). You also found that the use of vectors is an easy way to determine just what takes place when there is a change in frequency, resistance, capacitance, or inductance. So, if you have a question about the results, construct the vectors.

8-28. Tables 8-1, 8-2 and 8-3 are for explanation purposes, DO NOT MEMORIZE THEM. Instead, use vectors, formula and/or figure 8-4 to analyze the circuit.

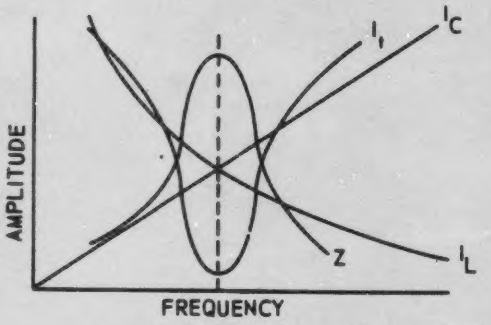

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Figure 8-4

Table 8-3

STARTING ABOVE RESONANCE

Increase in	Current Will	Impedance Will	Phase Angle Will
Frequency	Increase	Decrease	Increase
Resistance	Decrease	Increase	Increase
Capacitance	Increase	Decrease	Increase
Inductance	Increase	Decrease	Increase

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Chapter 9

TRANSIENTS

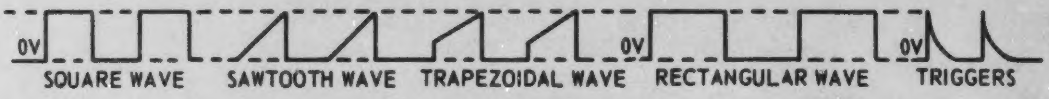
9-1. The function of many electronic circuits is waveshaping for timing or control. These waveshaping circuits must produce a variety of nonsinusoidal waveforms, such as square waves, sawtooth waves, trapezoidal waves, rectangular waves, and peaked waves or triggers (figure 9-1), whose duration and amplitude can be controlled with respect to TIME. Proper operation of a waveshaping circuit depends upon the circuit's response to a transient voltage or current. This chapter discusses transients in RC and RL series circuits.

9-2. A TRANSIENT voltage (or current) is the rapid change of voltage (or current) from one steady state to another steady state. The time allowed for the transient action is called the TRANSIENT INTERVAL. The waveshape may be observed as a graph by plotting amplitude relative to time.

9-3. A simple capacitor consists of two plates separated by insulating material known as dielectric. CAPACITANCE is the characteristic of a circuit or component which enables it to store an electrical charge. Charges are developed when electrons are moved from one place to another resulting in an excess of negative charge at one point and a deficiency of negative charge at the other. Electrons cannot be moved instantaneously. All capacitors take time to charge. The time required for a capacitor to charge depends on the amount of resistance through which the charging current flows, and on the size of the capacitor.

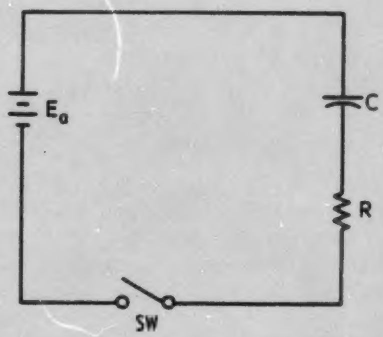
9-4. Figure 9-2 shows a simple series circuit with a battery, resistor, capacitor, and switch. When the switch is closed, the series battery voltage is applied across the RC circuit. Since C has no charge at the first instant, the initial charging is limited only by the size of R. The charging current flowing into C starts to accumulate. The accumulating charge appears as a voltage drop across C.

9-5. As the voltage across the capacitor increases, the voltage across the resistor decreases. It is the voltage across the resistor and the amount of resistance that



REP4-90

Figure 9-1



REP4-91

Figure 9-2

determine the charging current. The resistor value affects the charging current and, therefore, the time required to charge the capacitor. Capacitor size also affects charging time. The larger the capacitor, the more time required to charge it to a given voltage.

9-6. We have said that resistance affects the charging time of a capacitor. In addition, the value of the capacitor affected the charging time. You may remember from an earlier lesson that the relationship between charge, voltage, and capacitance was expressed as $Q = EC$. According to this equation if we hold E constant, and increase capacitance we increase the number of electrons required to charge the capacitor to that given voltage. Since more electrons are required to charge a larger capacitor; and, since the rate of the charging current is determined by the apppied voltage and circuit resistance, it is obvious that more time is required to charge a larger capacitor. The reverse is true if capacitance is decreased.

9-7. The applied voltage does not affect the time required to charge a capacitor. Whenever the applied voltage changes, the charging current changes a proportional amount, and the charging time is not affected.

9-8. The amount of resistance and capacitance are the only factors which determine the time required for a capacitor to charge to a given percentage of the applied voltage. The same holds true for the time required for a capacitor to discharge. Since time, resistance, and capacitance are related, we can express this relationship mathematically as $TC = R x C$ where TC is in seconds, R is in ohms, and C is in farads. The product of R times C is called a TIME CONSTANT.

9-9. A time constant in an RC circuit is the time it would take a capacitor to charge to the applied voltage IF IT CONTINUED TO CHARGE AT ITS INITIAL RATE. However, as the capacitor charges, the charging current decreases, and the rate of charge decreases. The result is that a capacitor only charges to about 63% of the applied voltage in one time constant (R x C). Because of this, A TIME CONSTANT IS DEFINED AS THE TIME REQUIRED FOR A CAPACITOR TO CHARGE TO 63% OF THE APPLIED VOLTAGE.

9-10. During the first time constant, the capacitor will charge to 63% of the applied voltage. Since this capacitor voltage then opposes the applied voltage, the difference between the applied and capacitor voltage (100% - 63% = 37%) is termed the AVAILABLE voltage. During the second time constant, the capacitor will charge to 63% of the AVAILABLE voltage. This AVAILABLE voltage is 37% of the applied, so 37% x 63% = 23.3%. To find what percentage of the applied voltage the capacitor has charged, simply add the percentages of these two charges, so 63% + 23.3% = 86.3%. Repeating this process we find the capacitor charged to the following levels for the following:

Third time constant -

13.7% x 63.0% = 8.6%
8.6% + 86.3% = 94.9%

Fourth time constant -

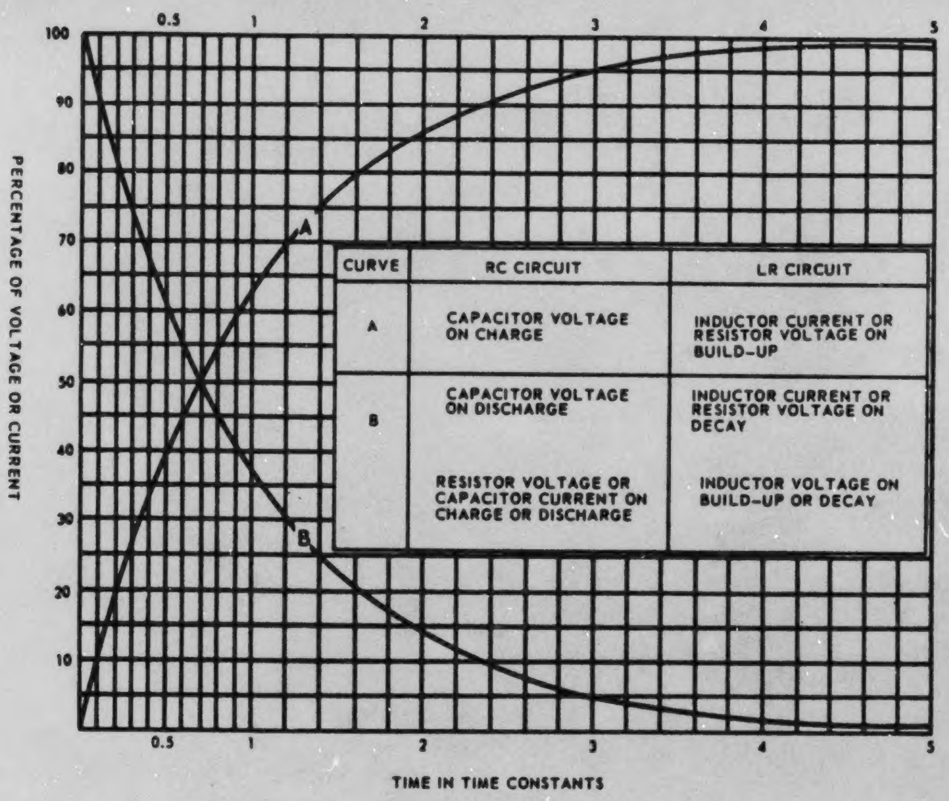
5.1% x 63.0% = 3.2%
3.2% + 94.9% = 98.1%

Fifth time constant -

1.9% x 63.0% = 1.2%
1.2% + 98.1% = 99.3%

9-11. Theoretically, the capacitor will never acquire a full charge. However, the difference between the voltage applied and the capacitor charge is negligible after five time constants. Therefore, it is assumed that A CAPACITOR IS FULLY CHARGED AFTER FIVE TIME CONSTANTS (5 TC).

9-12. Keeping the same values of R and C, the capacitor will always charge fully in the same period of time regardless of the magnitude of the applied voltage. Applied voltage will, however, determine the RATE of charge. By RATE we mean the rapidity with which the voltage across the capacitor builds up. It is this rate change that enables a capacitor to fully charge in the same period of time despite variations of applied voltage.



CURVE	RC CIRCUIT	LR CIRCUIT
A	CAPACITOR VOLTAGE ON CHARGE	INDUCTOR CURRENT OR RESISTOR VOLTAGE ON BUILD-UP
B	CAPACITOR VOLTAGE ON DISCHARGE	INDUCTOR CURRENT OR RESISTOR VOLTAGE ON DECAY
	RESISTOR VOLTAGE OR CAPACITOR CURRENT ON CHARGE OR DISCHARGE	INDUCTOR VOLTAGE ON BUILD-UP OR DECAY

UNIVERSAL EXPONENTIAL CURVES FOR RC AND LR CIRCUITS

Figure 9-3

The only way the capacitor's full charge time can be changed is by varying the time constant.

9-13. The opposite of the above is also true. A capacitor will discharge 63% during one time constant, 86.3% in two, 94.9% in three, 98.1% in four, and fully discharge in five time constants. Variations in the magnitude of voltage to which the capacitor is charged will only affect the RATE of discharge. Its discharge Time can be changed only by varying the time constant.

9-14. Remember: Variations in applied voltage can change only the RATE a capacitor charges or discharges. Despite any such variations, a capacitor will always charge to 63% of the applied voltage or discharge a like percentage during one time constant. By the same token, a capacitor will always fully charge or discharge in five time constants.

9-15. Since a capacitor charges or discharges 63% of the AVAILABLE voltage during each time constant, a chart showing this change in percentage of voltage versus number of time constants can be plotted and used for all series RC circuits. Such a chart has been prepared for you and it is known as a UNIVERSAL TIME CONSTANT CHART. By knowing how to read the chart, you can determine the voltage across any component and the circuit current at any instant. Likewise, you will be able to determine the time required for the circuit current (or the voltage across a component) to reach a given value.

9-16. A UNIVERSAL TIME CONSTANT CHART is shown in figure 9-3. Notice that the horizontal axis indicates the number of time constants and that the vertical axis indicates the PERCENT of voltage or current. The exponential curves, "A" and "B" were plotted by calculating the instantaneous capacitor voltage at many points during charge and discharge and connecting the points with a smooth curve. At the end of five time constants, the "A" curve is so near 100% we consider the capacitor fully charged and the "B" curve is so near 0% that we consider the capacitor fully discharged.

9-17. Before using the chart, we must consider one more time element - the time that the capacitor will be allowed to charge or discharge. The numbers along the horizontal axis of the chart represent the number of time constants (R x C) in the time allowed (t) for the charge or discharge of the capacitor. Mathematically, the number of time constants equals the time allowed for charge or discharge divided by the time constant of the circuit. As an equation:

$$\#TC = \frac{t}{R x C}$$

where

#TC = number of time constants

t = time allowed for charge or discharge (seconds)

R = the resistance of the circuit (ohms)

C = the capacitance of the circuit (farads)

9-18. For RC circuits on charge, the percent of available voltage to which the capacitor has charged is read on the "A" curve. The percent of available voltage across the resistor and the percent of maximum circuit current are read on the "B" curve. Note that when the reading is taken from the "B" curve that you are starting with 100%, so that the percentage reading is that percentage of voltage REMAINING across the components or the percentage of current remaining in the circuit. If in one time constant the voltage decreases 63%, then 37% remains across the component.

9-19. The functions of the "A" and "B" curves as used in RC circuits are summarized in the chart shown in figure 9-4.

A CURVE
E_C on capacitor charge
B CURVE
E_R on capacitor charge
I on capacitor charge
E_C on capacitor discharge
E_R on capacitor discharge
I on capacitor discharge

REP4-93

Figure 9-4

9-20. One efficient way to learn to use the time constant chart is by solving problems. Transient problems fall into three general categories:

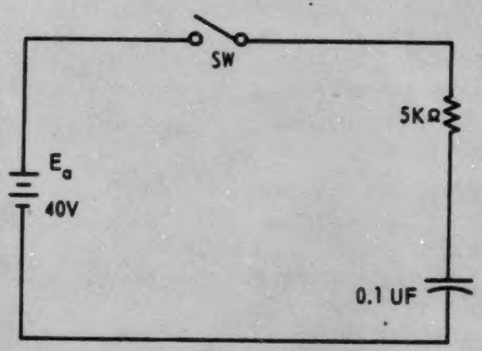
1. Determining circuit current and component voltages after a given time.

2. Determining the time required for circuit current and component voltages to reach a given value.

3. Determining component values required for the circuit current and component voltages to reach a given value in a given time.

9-21. PROBLEM 1

9-22. Using the circuit values of figure 9-5, compute the time constant, determine



REP4-94

Figure 9-5

the percent of charge on the capacitor, the voltages across the capacitor and resistor, and circuit current 1200 microseconds after the switch is closed.

Step 1: List what is given and what is to be found.

Given: $E_a = 40$ volts

$R = 5$ k ohms

$C = 0.1$ microfarads

$t = 1200$ microseconds

Find:

Time Constant = ______________

#TC = ______________

% of Charge = ______________

E_C = ______________

E_R = ______________

I = ______________

Step 2: Compute the time constant.

$$\begin{aligned} TC &= R \times C \\ &= 5 \times 10^{3} \times .1 \times 10^{-6} \\ &= .5 \times 10^{-3} \\ &= 500 \times 10^{-6} \text{ seconds} \end{aligned}$$

Step 3: Compute the number of time constants in the time allowed.

$$\begin{aligned} \#TC &= \frac{t}{R \times C} \\ &= \frac{1200 \times 10^{-6}}{500 \times 10^{-6}} \\ &= 2.4 \end{aligned}$$

Step 4: Locate 2.4 time constants on the horizontal axis of the time constant chart. Move up the 2.4 line until it intersects curve "A." From the intersection, read left to the vertical axis of the time constant chart and determine the percent of charge (voltage) across the capacitor. For this example you will find this percentage to be 91%.

Step 5: Calculate the capacitor voltage.

$$\begin{aligned} E_C &= 91\% \times E_a \\ &= .91 \times 40V \\ &= 36.4 \text{ volts} \end{aligned}$$

Step 6: Calculate resistor voltage.

$$\begin{aligned} E_R &= E_a - E_C \\ &= 40\text{ V} - 36.4\text{ V} \\ &= 3.6 \text{ volts} \end{aligned}$$

Step 7: Calculate circuit current. Since current is the same at all points in a series circuit, resistor current is circuit current.

$$\begin{aligned} I &= \frac{E_R}{R} \\ &= \frac{3.6V}{5 \text{ k ohms}} \\ &= .72 \text{ mA} \end{aligned}$$

9-23. In the preceding problem we used the time constant chart to determine the circuit current and component voltages after a given time. We are now going to use the time constant chart to determine the number of time constants required for the capacitor voltage to reach a given value of the available voltage.

9-24. PROBLEM 2

9-25. Use the circuit values of figure 9-6. The capacitor is uncharged. After the switch is closed, how many time constants are required for the capacitor voltage to rise to 30 volts?

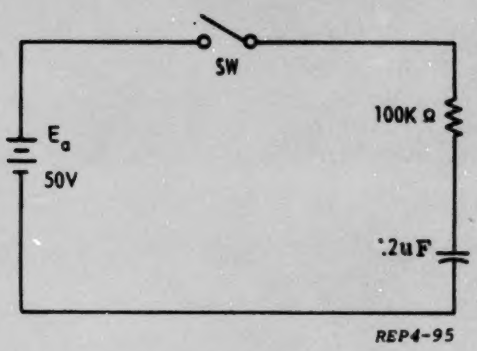


Figure 9-6

PROCEDURE

Step 1: List what is given and what is to be found.

Given: E_a = 50 volts

R = 100 k ohms

C = .2 microfarads

Find: Number of time constants required for E_C to reach 30V.

Step 2: Determine the percentage of the available voltage that will be across the capacitor by dividing the capacitor voltage by the available voltage, and multiply the quotient by 100.

$$\frac{30\text{ V}}{50\text{ V}} = .6 \times 100 = 60\%$$

Step 3: Using the time constant chart, move up the vertical axis until you reach 60%. Since the capacitor was charging, move to the right along the 60 percent line until you intersect the "A" curve. At the intersection read down to the horizontal axis to find the number of time constants. For this problem, you will find the number of time constants to be .9.

9-26. PROBLEM 3

9-27. In figure 9-7 switch 1 is closed, until the capacitor is charged to the available voltage, then opened. Find the percent of discharge of the capacitor, capacitor voltage, resistor voltage, and circuit current 130 microseconds after switch 2 is closed.

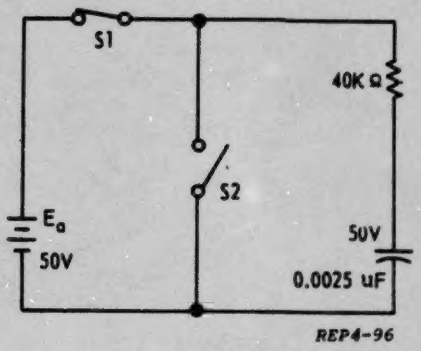


Figure 9-7

PROCEDURE

Step 1. List what is given and what is to be found.

Given: E_a = 50 V

E_C = 50 V

E_R = 0 V

R = 40 k ohms

t = 130 microseconds

C = 0.0025 microfarads

Find: #TC = ______________

% of Discharge = ______________

E_C = ______________

E_R = ______________

I = ______________

Step 2: Determine the number of time constants in the time allowed.

$$\#TC = \frac{t}{R \times C} = \frac{(130 \times 10^{-6})}{(40 \times 10^{3})\,(0.0025 \times 10^{-6})}$$

$$= 1.3$$

Step 3: Locate 1.3 time constants on the horizontal axis of the time constant chart. On discharge, the capacitor voltage is read on the "B" curve, so move up the 1.3 time constant line until you intersect the "B" curve.

Step 4: At the intersection of the 1.3 time constant line and the "B" curve, read to the left to determine the percentage of voltage remaining on the capacitor. The percentage remaining is 27.5 percent.

Step 5: Determine the remaining capacitor voltage.

$$E_C = 50\text{ V} \times .275$$
$$= 13.75\text{ V}$$

Step 6: Since the capacitor is acting as a power supply during discharge, the resistor voltage is equal to the capacitor voltage or 13.75 V.

Step 7: Calculate circuit current. As the circuit is a series circuit, the resistor current will be the circuit current.

$$I = \frac{E_R}{R} = \frac{13.75\text{ V}}{40\text{ k}\Omega} = .344\text{ mA}$$

Step 8: Determine the percent of discharge of the capacitor. Locate 1.3 time constants on the chart. On the "A" curve read the percent of discharge as 72.5%.

9-28. PROBLEM 4

9-29. Find the resistance of R in figure 9-8 if the capacitor charges to 50 volts in 1000 microseconds.

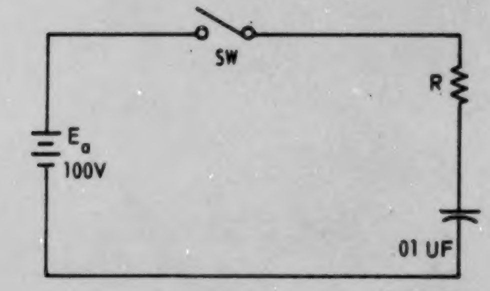


Figure 9-8

PROCEDURE:

Step 1: List what is given and what is to be found.

Given: $E_a = 100$ V

$E_C = 50$ V

$t = 1000$ microseconds

$C = 0.01$ microfarads

Find: $R =$

Step 2: Find what percentage of the available voltage is across the capacitor by dividing th capacitor voltage by the available voltage and multiplying by 100.

$$\frac{E_C}{E_a} = \frac{50\text{ V}}{100\text{ V}} \times 100 = 50\%$$

Step 3: Use the time constant chart to find the number of time constants required for the capacitor to charge to 50% of the applied voltage. Move up the vertical axis of the time constant chart to the 50% mark then move right to the intersection of the "A" curve. From this point, read down to the horizontal axis. The number of time constants is 0.7.

Step 4: Use the equation for the number of time constants to solve for R.

$$\#TC = \frac{t}{R \times C}$$

transposing:

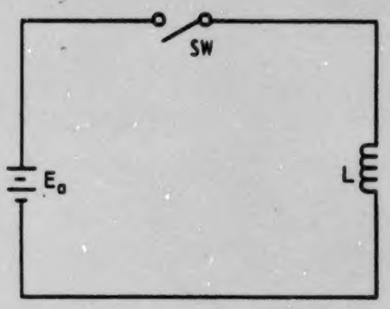
$$R = \frac{t}{\#TC \times C}$$

substituting:

$$R = \frac{(1000 \times 10^{-6})}{0.7 \times (0.01 \times 10^{-6})} = 142.8\text{ k ohms}$$

9-30 Deleted.

9-31. Deleted.



REP4-100

Figure 9-9

9-32. Deleted.

9-33. Deleted.

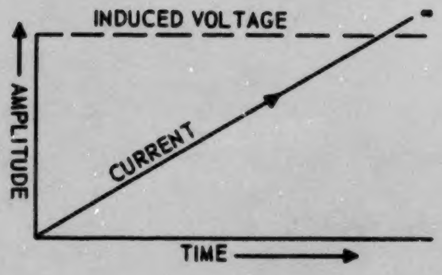
9-34. LR Problems

9-35. Just as the voltage across a capacitor, due to the charge in the capacitor, is in opposition to the applied voltage, the voltage induced in an inductor, resulting from a change in current through the inductor, is in opposition to the applied voltage.

9-36. In an RL circuit, the current through the inductor, which is proportional to the energy stored in the magnetic field, cannot change instantaneously with a change in applied voltage.

9-37. The circuit in figure 9-9 is assumed to have no resistance. When the switch is closed, current starts to flow, causing an expanding magnetic field which induces an opposing EMF. With no resistance in the circuit, current will increase at a rate which will cause the induced voltage to equal the applied voltage. The current must increase at a constant rate if a constant voltage is to be induced.

9-38. Unlike current rise in a purely inductive circuit, the resistance in a series LR circuit prevents a linear rise in current. See figure 9-11. As the current increases, an increasing voltage drop across the resistor produces a decreasing voltage drop across the coil. The transient current in an LR circuit increases at a CONTINUALLY DECREASING RATE until the rate of change becomes zero. The rate of current change becomes zero when the current reaches its maximum value and all of the applied voltage is dropped across the resistor. The "A" curve of the universal time constant chart (figure 9-12) may be used to determine current build-up in LR circuits. Since the current through and the voltage across a resistor are in phase, resistor voltage on build-up is also shown by the "A" curve. The inductor acts as an open circuit at the first instant a voltage is applied; therefore, on build-up, the inductor voltage is read on the "B" curve.

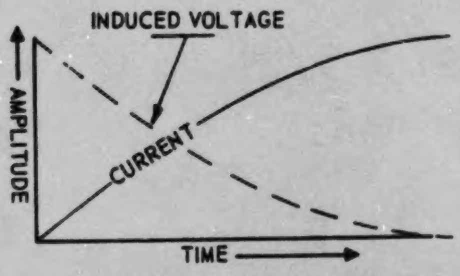


REP4-101

Figure 9-10

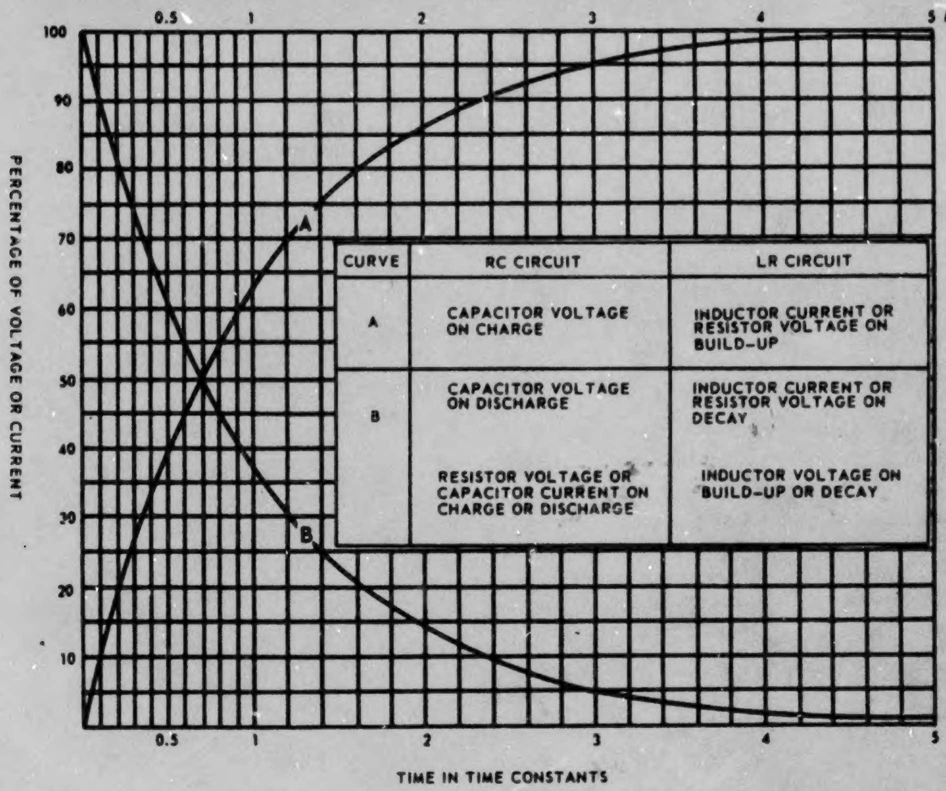
9-39. The inductor acts as the power source during the decay of the electromagnetic field; therefore, during decay, the current, resistor voltage, and inductor voltage are read on the "B" curve. Figure 9-13 summarizes this action.

9-40. Having established the relationship of the "A" and "B" curves of the universal



REP4-101

Figure 9-11



CURVE	RC CIRCUIT	LR CIRCUIT
A	CAPACITOR VOLTAGE ON CHARGE	INDUCTOR CURRENT OR RESISTOR VOLTAGE ON BUILD-UP
B	CAPACITOR VOLTAGE ON DISCHARGE	INDUCTOR CURRENT OR RESISTOR VOLTAGE ON DECAY
	RESISTOR VOLTAGE OR CAPACITOR CURRENT ON CHARGE OR DISCHARGE	INDUCTOR VOLTAGE ON BUILD-UP OR DECAY

UNIVERSAL EXPONENTIAL CURVES FOR RC AND LR CIRCUITS

Figure 9-12

time constant chart to the transient response of an LR circuit, let us examine the two factors controlling the transient response: (1) inductance and (2) resistance.

9-41. If the inductance is made larger, there will be more opposition to a CHANGE in current flow. It will take longer for the current to reach its maximum value. Therefore, the TIME for current build-up is DIRECTLY PROPORTIONAL TO THE AMOUNT OF INDUCTANCE.

9-42. If the resistance is made larger, the maximum value of current will be less. If the maximum value of current is less, the time required to reach maximum will also be less. Therefore, the TIME for current build-up is INVERSELY PROPORTIONAL TO THE AMOUNT OF RESISTANCE.

A CURVE

E_R on field build-up

I on field build-up

B CURVE

E_L on field build-up

E_L on field collapse

E_R on field collapse

I on field collapse

REP4-106

Figure 9-13

9-43. The time is proportional to L divided by R and is called a TIME CONSTANT. In equation form:

$$TC = \frac{L}{R}$$

where

TC = time for one time constant in seconds.
L = inductance in henries
R = resistance in ohms

9-44. In one time constant the current will build up to 63% of the maximum current. At the end of two time constants, current will have reached 86% of its maximum value. The current rise in the LR circuit is comparable to the rise of capacitor voltage in an RC circuit, and current is considered to reach its maximum value in five time constants. Likewise, the current is considered to reach zero in five time constants when the electomagnetic field is allowed to decay.

9-45. Having established the time of one time constant, we must now consider the time allowed for the current to build up or decay. Remember that the numbers along the horizontal axis of the time constant chart represent the number of time constants allowed for the current build-up or decay. As an equation:

$$\#TC = \frac{t}{L/R}$$

simplified:

$$\#TC = \frac{Rxt}{L}$$

#TC = number of time constants

t = time allowed for build-up or decay (seconds)

R = the resistance of the circuit (ohms)

L = the inductance of the circuit (henries)

9-46. Again we will use problem solving to apply the universal time constant chart to LR transient circuits.

9-47. PROBLEM 1

9-48. Find the percent of current build-up, the value of the current, the resistor voltage, and the inductor voltage, 2800 microseconds after the switch is closed in figure 9-14.

PROCEDURE

Step 1: Determine what is given and what is to be found.

Given: E_a = 50 V

L = 10 H

R = 10 k ohms

t = 2800 microseconds

Find: #TC =

% of I =

I_{max} =

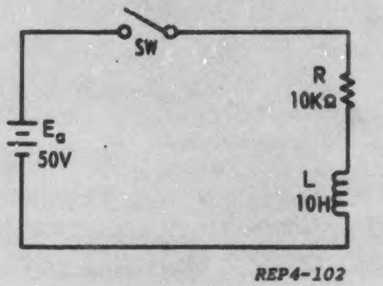
I =

E_R =

E_L =

Step 2: Find the number of time constants in the time allowed.

$$\#TC = \frac{R \times t}{L}$$



REP4-102

Figure 9-14

$$= \frac{(10 \times 10^3)(2800 \times 10^{-6})}{10}$$

$$= 2.8$$

Step 3: Using the time constant chart, go to the 2.8 time constant mark and then move up to the intersection of the "A" curve. Read left to the vertical axis to find the percentage of current build-up, which is 94% of maximum.

Step 4: Since the maximum current will be reached when all the available voltage is across the resistor, the maximum current may be calculated by Ohm's Law where:

$$I_{max} = \frac{E_a}{R}$$

$$= \frac{50V}{10\,k\,\Omega}$$

$$= 5\text{ mA}$$

Step 5: Find what value of current is 94% of 5 mA. This will be the current at the end of 2800 microseconds.

$$I = .94 \times 5\text{ mA} = 4.7\text{ mA}$$

Step 6: Calculate the voltage across the resistor at the end of 2800 microseconds by Ohm's Law.

$$E_R = I \times R$$

$$= (4.7 \times 10^{-3})(10 \times 10^3)$$

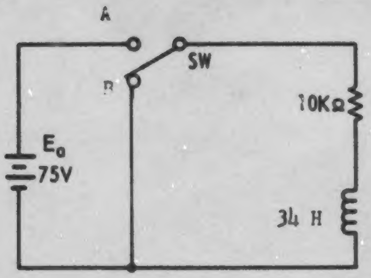
$$= 47\text{ V}$$

Step 7: Calculate the voltage across the inductor at the end of 2800 microseseconds by Kirchhoff's Law.

$$E_L = E_a - E_R$$

$$= 50\text{ V} - 47\text{ V}$$

$$= 3V$$



REP4-103

Figure 9-15

9-49. PROBLEM 2

9-50. In the figure 9-15, 1200 microseconds after the switch is moved from position "A" to position "B" the current will have decayed by what percent?

Step 1: List what is given and what is to be found.

Given: $E_a = 75$ V

$R = 10\text{ k }\Omega$

$L = 34$ H

$t = 1200$ microseconds

Find: Percent of current decay.

Step 2: Find the number of time constants in the time allowed.

$$\#TC = \frac{Rxt}{L}$$

$$= \frac{(10 \times 10^3)(1200 \times 10^{-6})}{34}$$

$$= .35$$

Step 3. Determine the percent of current decay. Locate .35 time constants on the chart. Move up to interect the "B" curve. Move left and read 70%. The percent of current decay is 30. (100% - 70% = 30%)

9-51. PROBLEM 3

9-52. In figure 9-16, the inductor voltage is 40 V, 1500 microseconds after the switch

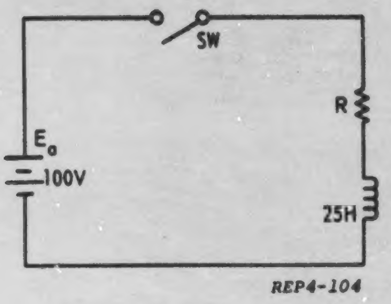


Figure 9-16

is closed. What is the ohmic value of the resistor?

PROCEDURE

Step 1: List what is given and what is to be found.

Given: $E_a = 100$ V

$E_L = 40$ V

$L = 25$ H

$t = 1500$ microswconds

Find: $R =$

Step 2: Find what percentage of the available voltage is represented by the inductor voltage.

$$\frac{E_L}{E_a} = \frac{40\text{V}}{100\text{ V}} \times 100 = 40\%$$

Step 3: Find the number of time constants required for the inductor voltage to change from 100 V to 40 V. Move up the vertical axis of the time constant chart to the 40% mark and then move right to the "B" curve. Read down to the horizontal axis to find the number of time constants, 0.94.

Step 4: Use the equation for number of time constants to solve for the resistance.

$$\#TC = \frac{R \times T}{L}$$

transposing:

$$R = \frac{\#TC \times L}{t}$$

$$= \frac{(.94)\,(25)}{1500 \times 10^{-6}}$$

$$= 15.7 \text{ k}\,\Omega$$

9-53. Deleted.

9-54. Figure 9-17A is a simple square wave generator. Switching from A to B then back to A in rapid succession will produce an output (figure 9-17B) that goes from 0V to 100V at the rate of switching. At time

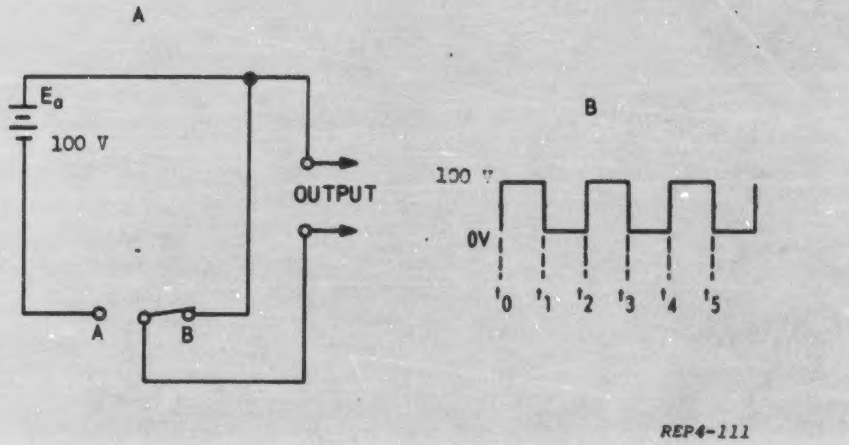
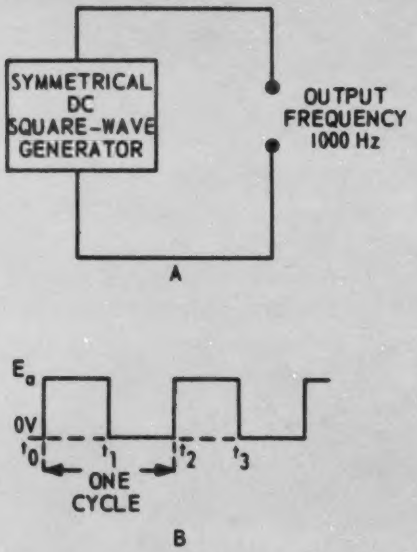


Figure 9-17



REP4-112

Figure 9-18

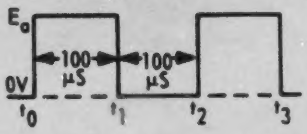
t_0 the switch is placed in position A and the voltage at the output jumps to 100 volts and remains at this value until time t_1, when the switch is thrown to position B. The voltage drops instantaneously to 0 volts and remains at that value until time t_2 when the switch is again placed in position A.

9-55. From t_0 to t_2 is one CYCLE, and the time cycle requires is called PULSE RE-current time (prt). The frequency is calculated by the equation:

$$f = \frac{1}{t}$$

where f equals the frequency in hertz and t equals the pulse recurrence time in seconds.

9-56. Each cycle consists of two alternations. T_0 to t_1 is the first alternation and t_1 to t_2 is the second alternation. If the two alternations are equal in time, the square wave is symmetrical. The time of one alternation of a symmetrical square wave is one half the time for one cycle. If frequency is known the time for one cycle can be determined by:



REP4-113

Figure 9-19

$$t = \frac{1}{f}$$

9-57. It is important to remember that the time t is the time for one cycle. Therefore, if you want the time for one alternation, the answer must be divided by two.

For clarity, let's work two problems.

9-58. The frequency of the output of a square wave generator as shown in figure 9-18 is 1000 Hz. Find the time of one cycle and one alternation.

$$t = \frac{1}{f}$$

$$= \frac{1}{1000}$$

$$= .001 \text{ seconds}$$

$$= 1000 \text{ microseconds}$$

As the 1000 microseconds represents the PRT, each alternation will be 500 microseconds.

9-59. In the output waveform shown in figure 9-19, the time of each alternation is 100 microseconds. Find the frequency of the square wave.

$$t = 100\,\mu s + 100\,\mu s$$

$$= 200\,\mu s$$

$$f = \frac{1}{200 \times 10^{-6}}$$

$$= 5000 \text{ Hz}$$

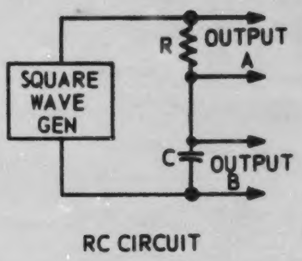
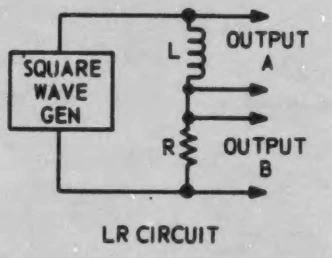


Figure 9-20



REP4-114

Figure 9-21

9-60. Time constants are classified as long, medium, or short. Is a week a long time, a medium time, or a short time? That depends on what you use for comparison. If you are waiting for a pay check, or an important letter, it is a long time; but if you are building a house or writing a book, it is a short time. The actual time duration of the week remains the same, but it can be a long time or a short time depending upon the standard to which it is compared.

9-61. So it is with a TIME CONSTANT. A time constant depends on the values of R and C in an RC circuit or the values of L and R in an LR circuit. The components of an RC or LR circuit by themselves do not determine whether the time constant is long or short. Whether the time constant is considered long or short depends on the time to which it is compared. Using a square-wave input, the time used for comparison would be the TIME (t) FOR ONE ALTERNATION. It is the relationship between the time (t) of the alternation and the time constant (TC) that is the determining factor. If the time constant (TC) is LONG in comparison to the time of one alternation, then the time constant is considered long. If the time constant is short in comparison to the time for one alternation, then it is classified as a SHORT time constant. Arbitrary limits have been established. When the ratio of $\frac{t}{TC} = \frac{1}{10}$ or less, the time constant is LONG. When the ratio of : $\frac{t}{TC} = \frac{10}{1}$ or more, the time constant is SHORT. Thus, a time constant of 10,000 microseconds may be a short time constant in one case, while a time constant of 50 microseconds may be a long time constant in another.

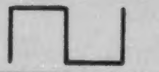
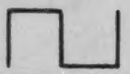
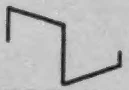
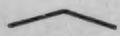
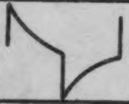
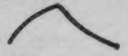
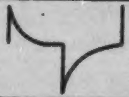
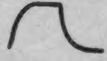
9-62. All time constants between these limits are medium time constants. That is if $\frac{t}{TC}$ is greater than $\frac{1}{10}$ but less than $\frac{10}{1}$ the time constant is MEDIUM.

9-63. Deleted.

9-64. If a square wave is applied to an RC circuit (figure 9-20), the output can be taken across the capacitor or the resistor. Likewise, if an LR circuit (figure 9-21) is used, the output can be taken across either L or R. The waveshape across any of the components will depend on the time constant of the circuit.

9-65. Figure 9-22 summarizes the output waveshapes where a square-wave input is applied to an RC or an LR circuit.

9-66. In example 1 (long time constant), OUTPUT A is taken across R in an RC circuit and L in an LR circuit. Notice that it has almost the same shape and amplitude as the input. OUTPUT B (across C in the RC circuit and R in the LR circuit) is greatly distorted. It is a triangular wave with a very small amplitude.

		OUTPUT "A" E_r IN RC CIRCUIT E_L IN LR CIRCUIT	OUTPUT "B" E_c IN RC CIRCUIT E_r IN LR CIRCUIT
	INPUT WAVE		
EX 1	LONG TIME CONSTANT T/RC OR RT/L = 0.1 OR LESS		
EX 2	MEDIUM TIME CONSTANT		
EX 3	SHORT TIME CONSTANT T/RC OR RT/L = 10 OR MORE		

REP4-115

Figure 9-22

9-67. In example 2 (medium time constant), OUTPUT A is distorted with a peak-to-peak amplitude greater than the input. OUTPUT B is also distorted but less than in example 1. The amplitude has increased and may be less than or equal to the input.

9-68. In example 3 (short time constant), OUTPUT A is greatly distorted into a peaked wave with a peak-to-peak amplitude of twice the input amplitude. OUTPUT B, however, has almost the same waveshape as the input, with an amplitude equal to the input.

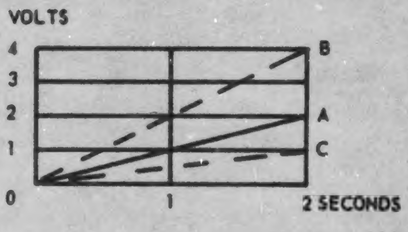
9-69. Thus, we can get a variety of output waveshapes with a square wave input by choosing proper component values for the RC or LR circuit.

9-70. Differentiation and Integration Circuits

9-71. In the introduction to this chapter, it was stated that in electronics the function of many circuits is to produce nonsinusoidal waveshapes. Two processes commonly used for waveshaping are differentiation and integration. Your knowledge of transient responses will help you understand how differentiation and integration provide a means for changing one type of waveshape to another type.

9-72. Differentiating circuits produce an output voltage that is proportional to the RATE OF CHANGE of the input, or HOW FAST the input is changing. A differentiating circuit uses a short time constant and the output is taken across the resistor in an RC circuit or the inductor in an LR circuit. See example 3, OUTPUT A, of figure 9-22.

9-73. RATE OF CHANGE. Just what is meant by "rate of change?" Let us plot a steadily increasing voltage against time. If the voltage increases 1 volt per second, the resulting graph would look like line A in figure 9-23. If the voltage increases 2 volts per



REP4-116

Figure 9-23

second, the graph would resemble line B. If on the other hand, the voltage changes only .5 volt/second, the graph would resemble line C. Which voltage is changing the fastest? Line B, of course, since it went from 0 to 4 volts in 2 seconds. Line C would represent the slowest change since it shows a change from 0 to 1 volts in 2 seconds. The SLOPE of the line then is an indication of how fast the voltage is changing. The steeper the slope, the greater the RATE OF CHANGE. A vertical line would mean maximum rate of change. Likewise, a horizontal line would mean zero rate of change or no change.

9-74. Deleted.

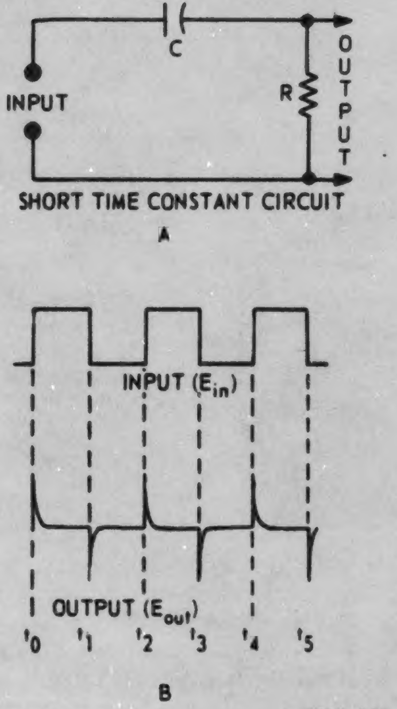
9-75. Figure 9-25 shows the effect of a differentiating circuit on a square wave input. At time t_0, the input changes rapidly from one steady state to another. The rate of change is maximum, and the output voltage is maximum. From t_0 to t_1 there is no change and the output drops to zero volts. How fast it drops to zero depends upon the time constant of the circuit. At time t_1, there is another sudden change of voltage in the opposite direction, and the output voltage is again maximum, but in the opposite direction. Look again at figure 9-22 (OUTPUT A in example 3) and note that you can get the same differentiated wave if you apply a square wave to a short time constant LR circuit with the output taken from across the inductor.

9-76. Deleted.

9-77. Integration

9-78. An integrating circuit produces an output voltage that is proportional to the area under the input waveform. Area equals voltage x time.

9-29. A practical means of producing an integrated waveshape is to employ a long time constant RC circuit and take the output across the capacitor. The same waveshape could be developed by using long time constant LR circuit and taking the output across the resistor. See example 1, output B in figure 9-22.



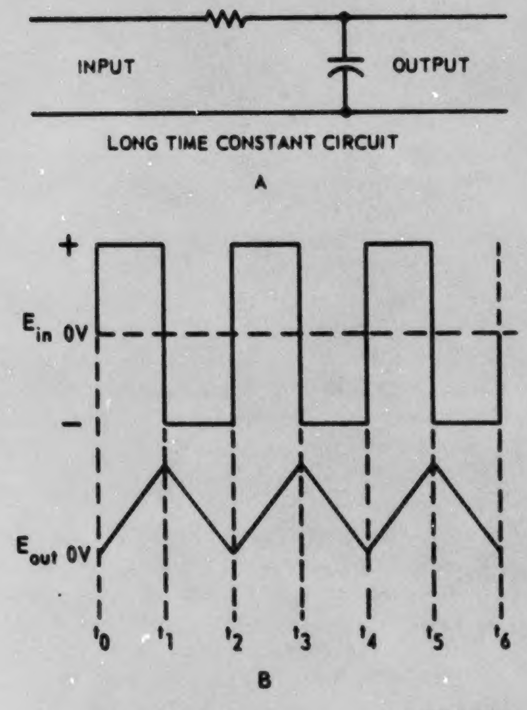
REP4-119

Figure 9-25

9-80. Deleted

9-81. In figure 9-28, at time t_0, the square wave input is zero and the charge on C1 is zero. As time progresses from t_0 to t_1, C1 charges toward the applied voltage producing an output that increases in amplitude. At time t_1 the input passes through zero and becomes negative. From t_1 to t_2, C1 discharges to zero and charges toward the applied negative voltage. At time t_2 the input waveform becomes positive and C1 discharges to zero and charges toward the applied positive voltage.

9-82. A summary of the results of differentiation and integration is indicated in figure 9-29. A square wave is shown; however, the circuits that have been described will handle any type of waveform.



REP4-122

Figure 9-28

9-83. Below are listed four brief statements that summarize what has been covered on RC and LR circuits.

a. An RC circuit is a differentiating circuit if the time constant is short and the output wave is taken from across the resistor.

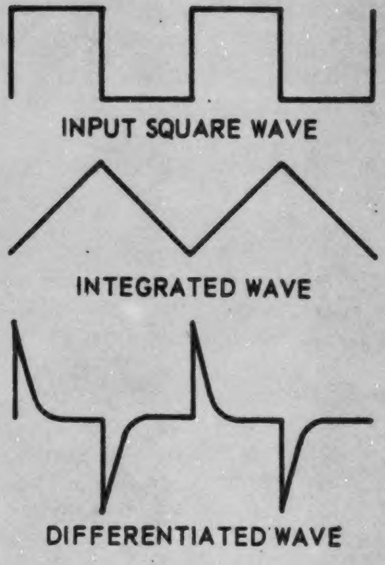
b. An LR circuit is a differentiating circuit if the time constant is short and the output wave is taken across the inductor.

c. An RC circuit is an integrating circuit if the time constant is long and the output wave is taken across the capacitor.

d. An LR circuit is an integrating circuit if the time constant is long and the output wave is taken across the resistor.

9-84. In this chapter, you reviewed the characteristics of resistors, capacitors, and inductors; and you learned that a transient voltage or current is a voltage or current changing from one steady state to another. The time required for this change is known as the transient interval, and the time and amplitude graph of the voltage or current is known as a waveshape.

9-85. In an RC series circuit you learned that the charge and discharge time of the capacitor is directly proportional to the value or resistance and capacitance, and the product of the resistance and capacitance is called a time constant. A time constant is the time required for the capacitor to charge to 63% of the AVAILABLE applied voltage. In each successive time constant the capacitor charges 63% of the REMAINING voltage. The



REP4-123

Figure 9-29

capacitor is considered fully charged after FIVE time constants. Conversely, a capacitor discharges 63% of the voltage remaining across it during a time constant and is said to be completely discharged after FIVE time constants. The Universal Time Constant Chart is a graph used to determine the percentage of charge or discharge of a capacitor plotted against the number of time constants. The vertical axis of the chart indicates the percentage of full voltage (or current) and the horizontal axis indicates the number of time constants. The number of time constants is calculated by dividing the time allowed (for the capacitor to charge or discharge) by the time constant (RC).

9-86. The use of the Universal Time Constant Chart was explained for RC series circuits. It was shown that on charge capacitor voltage is read on the "A" curve and that resistor voltage and current are read on the "B" curve. During discharge, all voltages and currents are read on the "B" curve.

9-87. The three general categories of transient problems were discussed:

a. Finding the percent of current and voltage after a given time.

b. Finding current and voltage after a given time.

c. Finding component values necessary for the current and voltage to reach a given value in a given time. Problems were solved for each category.

9-88. The values of the inductance and resistance determine the transient response of an LR circuit. Since the resistance limits the final or steady-state value of current in an LR circuit, it is a factor governing the rate of current change. The time constant of a series LR circuit is equal to the inductance expressed in henries divided by the resistance in ohms.

9-89. The use of the Universal Time Constant Chart with LR circuits was explained. It was established that on build-up, inductor voltage is read on the "B" curve and resistor voltage and current are read on the "A" curve. During decay, all voltages and currents are read on the "B" curve. Again problems were solved to determine LR circuit transient response.

9-90. You learned the characteristics of a DC symmetrical square wave with emphasis on the fact that the alternations are of the same duration. You calculated the time of a cycle when the frequency was known and calculated the frequency when the time of an alternation was known.

9-91. RC time constants were classified as long, short, or medium with respect to the time allowed for the capacitor to charge or discharge. A time constant is long when it is 10 or more times greater than the time allowed. A time constant is short when it is only one-tenth, or less, as long as the time allowed. All time constants between 10 times as long and one-tenth as long, are medium time constants. Time constant duration was emphasized by showing the waveshapes of long, short, and medium time constant circuits.

9-92. Two processes for changing one type of waveshape to another type were introduced: (1) differentiation and (2) integration. Differentiating circuits produce an output in proportion to the rate of change of the input. The circuit uses a short time constant with the output taken across the resistor in an RC circuit and across the inductor in an LR circuit. Integrating circuits produce an output proportional to the area under the curve. The circuit uses a long time constant with the output taken across the capacitor in an RC circuit and across the resistor in an LR circuit. We showed how one waveshape may be changed to another by differentiating or integrating a square wave.

Chapter 10

FILTERS

10-1. We will introduce filters using the series resonant circuit. But first we need to know what a filter is and why it is used. A filter is a circuit consisting of a number of impedances grouped together in such a way as to have a definite frequency characteristic. Filters are designed to pass a certain range of frequencies freely and to block another range of frequencies.

10-2. Filters make use of the variations of inductive and capacitive reactance with frequency. The variation of impedance in series RCL circuits is used to pass or reject certain bands of frequencies. The range over which passage occurs freely is called the bandpass; and the range over which poor passage occurs is called the attenuation band. The frequency at which attenuation starts to increase rapidly is known as the cutoff frequency.

10-3. Let's review and apply the basic principles of the frequency response characteristics of the capacitor and inductor. Recall the basic formula for capacitive reactance and inductive reactance.

$$X_C = \frac{1}{2\pi fC}$$

$$X_L = 2\pi fL$$

If we increase frequency, X_C decreases and X_L increases. If we increase frequency enough, the capacitor acts as a short and the inductor acts as an open. Of course the opposite is true; decreasing frequency causes X_C to increase and X_L to decrease. Here again, if we make a large enough change, the capacitor acts as an open and the inductor like a short. Figure 10-1 gives a pictorial representation of these two basic components. Note how they respond to low and high frequencies.

10-4. If we apply these same principles to simple circuits (see figure 10-2) they respond as shown for low and high frequencies.

10-5. Let's see how we can use the series resonant circuit as a filter. Refer to figure 10-3. We know that at resonance E_C and E_L are equal and opposite (180° out of phase); Z is minimum and current is maximum. If we take an output across the resistor when the circuit is at resonance, we get the maximum possible voltage ($E_R = E_a$). As we tune the generator to either side of resonance, the output will decrease. This is shown by the frequency response curve in figure 10-4.

10-6. The frequency response curve is for a BANDPASS filter (figure 10-4). The frequencies between the half power points pass to the next circuit. The other frequencies which fall below the lower half power point, and the ones above the upper half power point are filtered out; these two bands of

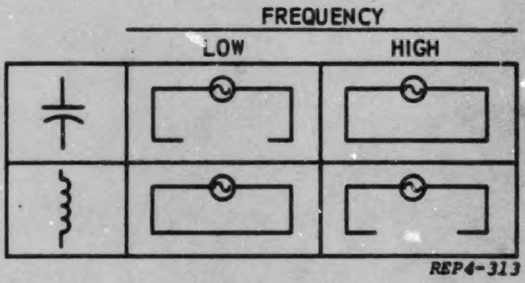


Figure 10-1

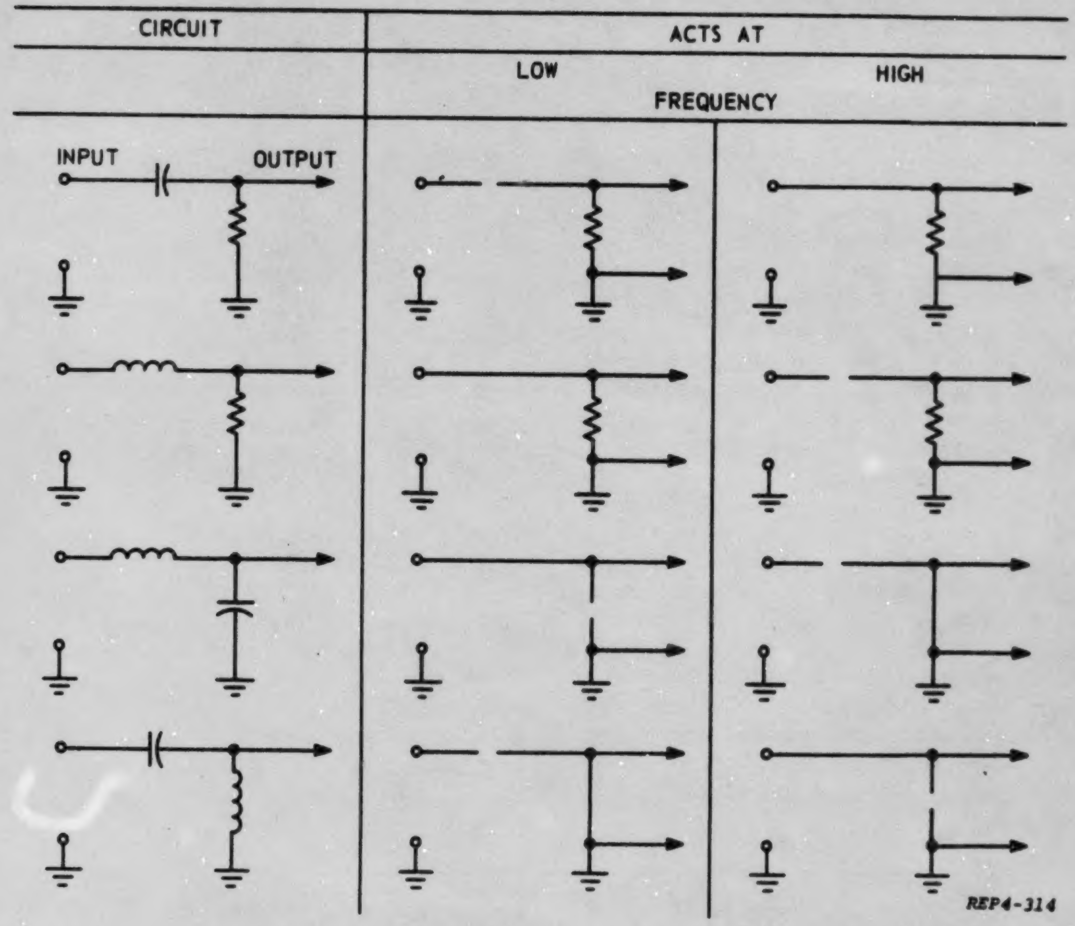

CIRCUIT
ACTS AT
LOW
HIGH
FREQUENCY
INPUT
OUTPUT
REP4-314

Figure 10-2

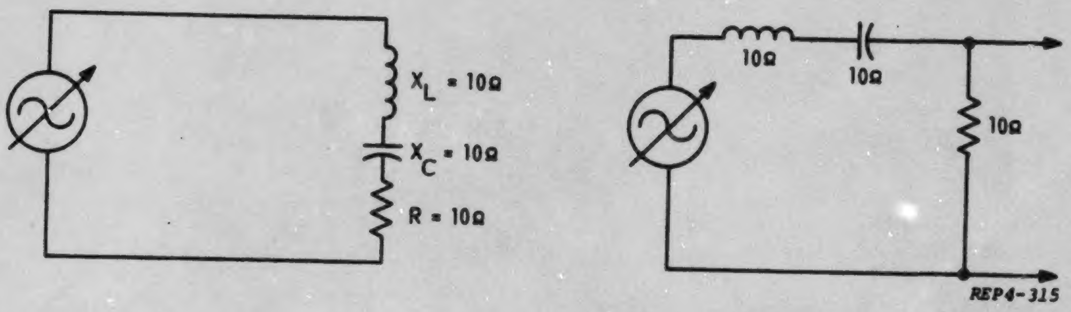

X_L = 10Ω
X_C = 10Ω
R = 10Ω
10Ω
10Ω
10Ω
REP4-315

Figure 10-3

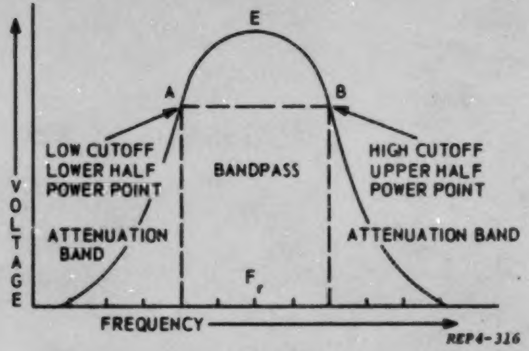


Figure 10-4

frequencies fall in the "attenuation" bands. The half power points are the cutoff frequencies.

10-7. If the output is taken across both the inductor and capacitor, the frequency response curve resembles figure 10-5. This is a BAND REJECT filter. Band reject filters are designed to reject a definite band of frequencies and pass all other frequencies. The LC portion of this circuit appears to the signal as a short at the resonant frequency, and an open for frequencies above and below resonance.

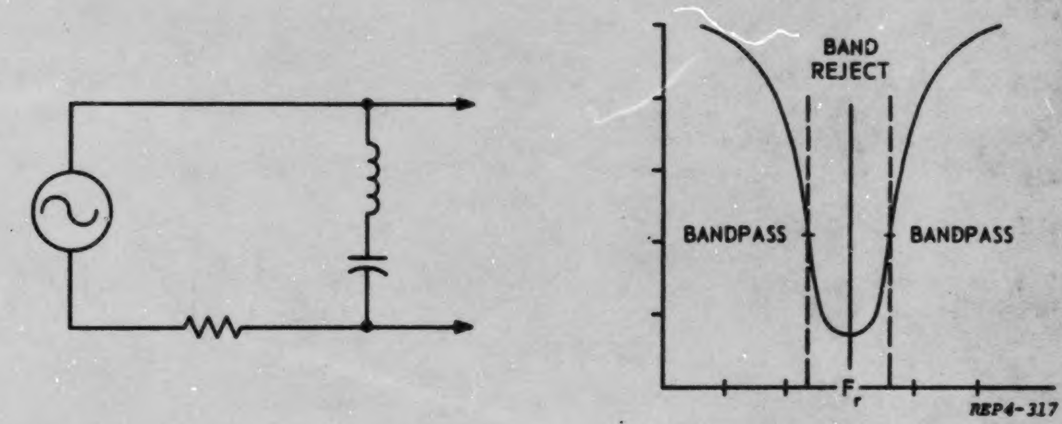


Figure 10-5

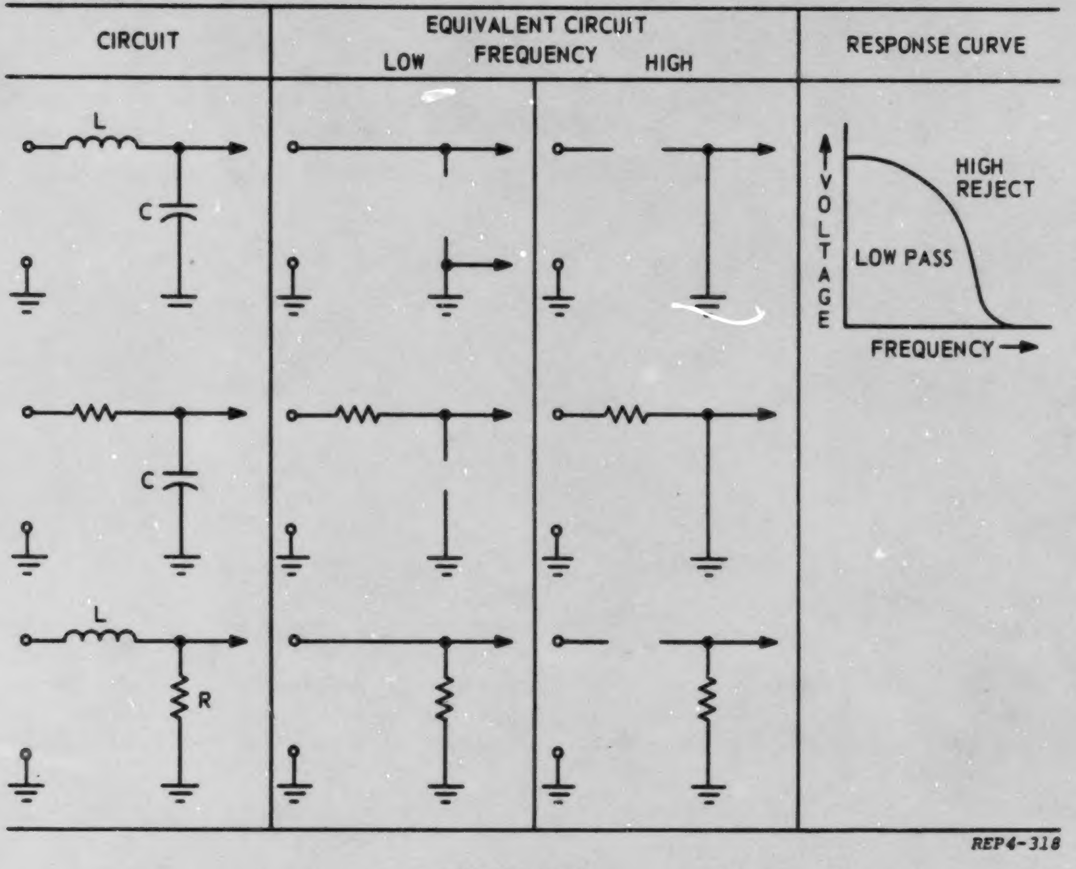


Figure 10-6

10-8. Another filter of major importance is the LOW PASS filter. This filter does exactly what the name implies; it passes low frequencies and rejects high frequencies. Some examples are shown in figure 10-6.

10-9. The other type filter is the HIGH PASS filter. Just opposite of the low pass, this filter passes high frequencies and rejects low frequencies. One example is shown in figure 10-7.

10-10. The basic configurations into which LOW PASS, HIGH PASS, BANDPASS, and BAND-REJECT filters are assembled are the L-SECTION, consisting of one series and one parallel arm; the T-SECTION, consisting of two series arms and one shunt arm; and the PI SECTION, consisting of one series arm and two shunt arms. Several sections of the same configuration can be joined to improve the attenuation or transmission characteristics. We will discuss single-section L-, T-, and Pi-type filters.

10-11. Deleted

10-12. Low Pass Filters

10-13. The L-, T-, and Pi-section types of low pass filters are shown in figure 10-8 A, B, and C. In this simple type filter, the series filter arm impedance is X_L, and the shunt filter arm impedance is X_C. The low pass filter shown has a gradual cutoff characteristic.

10-14. The formula for determining cutoff frequency is:

$$f_c = \frac{1}{\pi\sqrt{LC}}$$

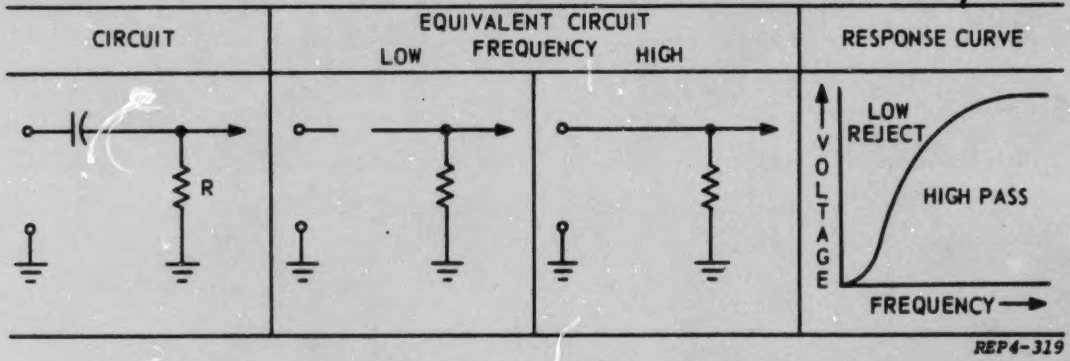


Figure 10-7

L and C are in henries and farads respectively. The low-pass filter passes frequencies below f_c freely; and attenuates all frequencies above the cutoff frequency. See figure 10-8D. To understand this action, you must take into consideration the basic characteristics of the inductor and capacitor.

10-15. In the L-section, LC, low-pass filter, figure 10-8A, the L and C form a frequency sensitive voltage divider. At low frequencies the reactance of the series inductor is low while the reactance of the shunt capacitor is high. Very little voltage is dropped across the low reactance of the inductor. Most of the applied voltage will be dropped across the high reactance of the capacitor. The voltage across the capacitor is applied to the load. At high frequencies most of the voltage will be dropped across the high reactance of the series inductor. Very little is dropped across the low reactance of the shunt capacitor. The low voltage drop across the capacitor is applied to the load. As frequency is increased, the voltage applied to the load will remain nearly constant up to the cutoff frequency of the filter. Above cutoff, the output of the filter drops rapidly (figure 10-8D).

10-16. Deleted

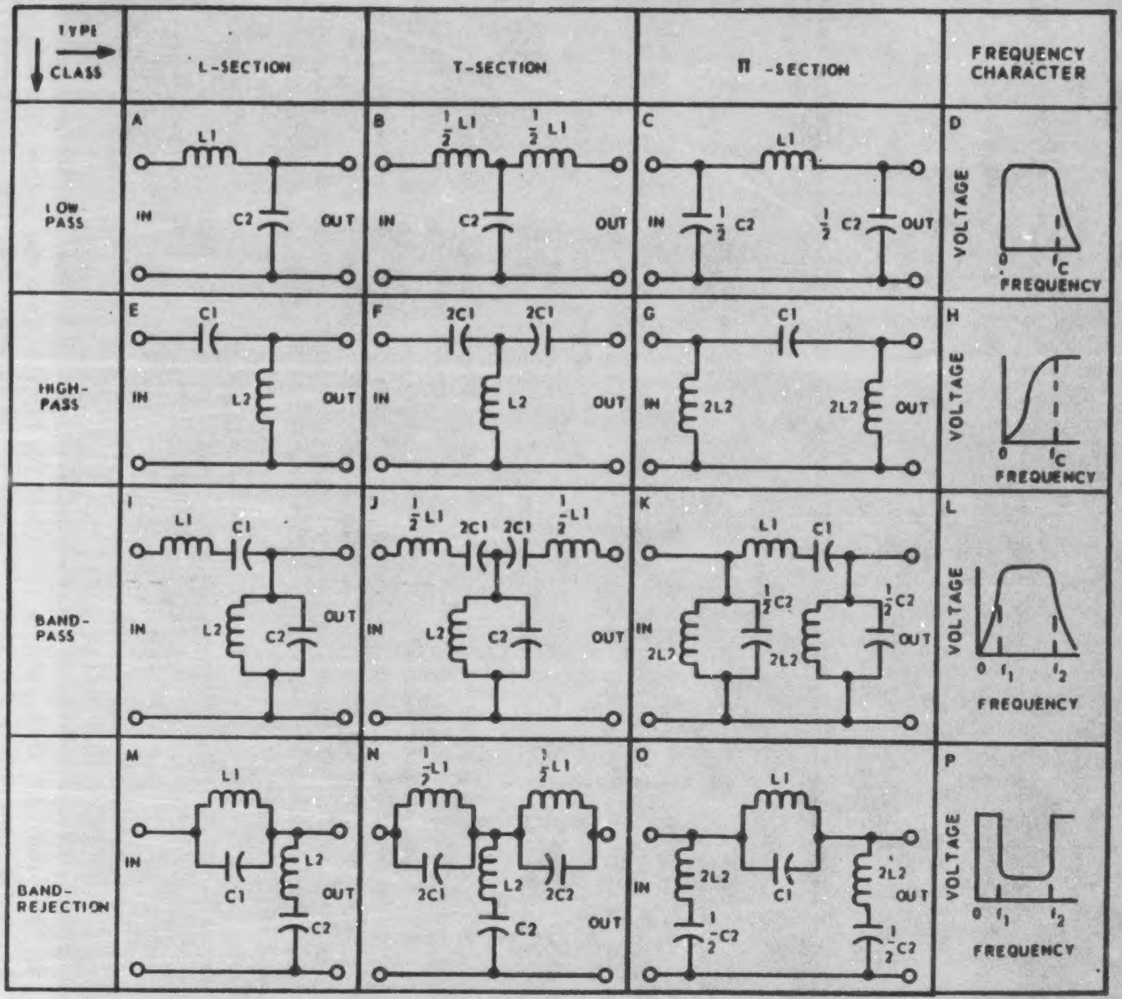
10-17. Deleted

10-18. Deleted

10-19. Deleted

10-20. To form the T-section low-pass filter (figure 10-8B), the coil of the L-section filter is divided into two equal parts and placed before and after the capacitor. Coils offer very little opposition to current at low frequencies. As the frequency increases, the inductive reactance increases; therefore, the coils offer a larger opposition to the flow of current. Any high frequency current that gets through the first coil passes through the capacitor, whose reactance to high frequencies is low, and does not reach the output. For low-frequency currents, the inductive reactance is small and the capacitive reactance is large. Accordingly, these currents readily pass through both coils to the load. This is shown graphically by the characteristic curve, figure 10-8D. Full values of L and C are used for the L-section; for the T section, the inductor value is halved as shown.

10-21. The Pi-type filter shown in figure 10-8C is formed from the L-type filter by dividing the capacitor into two equal parts; then placing one at each end of the coil. In this case, the high frequencies see a low-impedance path at the first filter capacitor; and a high attenuation at the series inductor. Any remaining high-frequency signals are then effectively shunted by the low impedance of the second (output) capacitor. The T- and Pi-type filter operation is identical to that of the L-section filter; but the T and Pi arrangements offer equal impedance when looking into the filter from the INPUT or OUTPUT terminals. For example, the T and Pi circuits filter equally well from either


TYPE
CLASS
L-SECTION
T-SECTION
π-SECTION
FREQUENCY CHARACTER
LOW PASS
HIGH-PASS
BAND-PASS
BAND-REJECTION
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
L1
C2
$\frac{1}{2}$ L1
$\frac{1}{2}$ C2
C1
L2
2C1
2L2
IN
OUT
VOLTAGE
FREQUENCY
0
f_C
f_1
f_2
$\frac{1}{2}$ C2
2C2

REP4-323

Figure 10-8

the IN or OUT terminals; you could swap input and output connections and have no change in filtering action. This is a symmetrical filter.

10-22. The L-section filter offers high impedance to a high frequency at the input side, but low impedance at the output side.

10-23. High-Pass Filters

10-24. The L-, T-, and Pi-section types of high-pass filters are shown in figure 10-E, F, and G. The high-pass filter, like the low-pass, has a gradual cutoff frequency.

10-25. High-pass filter circuits using inductance and capacitance have the same configurations as do the low-pass filters. By simply reversing the position of the components in the low-pass filter, it becomes a high-pass filter. For the L-section LC, high-pass filter, refer to figure 10-8E and H.

10-26. As you will notice the capacitor is now in series with the input signal; the inductor is in shunt. If the resonant frequency is applied to this circuit, the capacitor offers the same amount of opposition as the inductor. When the frequency goes below resonance, the capacitor will offer more series opposition and the inductor offers a shunt path of low opposition to ground. This reduces the signal that will reach the load.

10-27. The thing you should notice for the T-section high-pass filter is that the sizes of the capacitors are doubled. See figure 10-8F. The value of each capacitor is doubled so that the combination will offer the same opposition as in the L-section. Notice the value of the inductor has not changed. The same operational analysis applies to this circuit as the L-section.

10-28. For the Pi-section, high-pass filter, the inductors are doubled in value. See figure 10-8G. We have, in effect, two inductors in parallel; so the effective inductive reactance remains the same as in the other two high-pass filters.

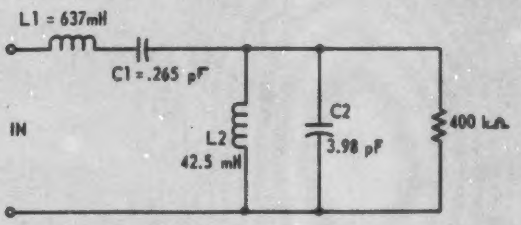
10-29. Deleted

10-30. Bandpass Filters

10-31. The L-, T-, and Pi-section types of bandpass filters are shown in figure 10-8I, J, and K. The Frequency characteristic of bandpass filters is shown in figure 10-8L. Refer to figure 10-8I for basic operation of the L-type bandpass filter: L1 and C1 form a series-resonant circuit and L2-C2 form a parallel-resonant circuit. The component sizes are selected so that each circuit will have the same resonant frequency.

10-32. At the resonant frequency, the series resonant circuit (L1, C1) offers minimum opposition to the signal. The parallel resonant circuit (L2, C2), offers maximum opposition to the signal. This means that maximum signal will pass to the load. If the applied signal frequency increases or decreases from resonant frequency, L1 and C1 offer a larger opposition and L2 and C2 offer less opposition. The bandpass filter has an upper and lower cutoff frequency (f_1 and f_2). These points determine what frequencies will pass to the load. Of course the values of the circuit components determine where these points will fall.

10-33. Figure 10-9 shows an L-section bandpass filter with the component values indicated. This filter will pass frequencies between 300 kHz and 500 kHz. Frequencies below 300 kHz and above 500 kHz will be attenuated.



REP4-322

10-34. Deleted

10-35. The T- and Pi-type bandpass filters, shown in figure 10-8J and K, function in the same manner as the L-type, but are symmetrical.

10-36. Band-Reject Filter

10-37. The frequency characteristic of band-rejection filters is shown in figure 10-8P. Refer to figure 10-8M for the schematic of the L-section band-reject filter.

10-38. Band-reject filters will reject a certain band of frequencies. Two resonant circuits are tuned to the center frequency of the rejected band. The parallel circuit, L1 and C1, offers maximum opposition to the resonant frequency. The series circuit, C2 and L2, offers minimum opposition to this same frequency. Thus, the energy that is not attenuated by L1-C1 is shorted back to the input through L2-C2.

10-39. The frequency response curve, figure 10-8P, shows that the band-reject filter also has two cutoff frequencies.

Chapter 11

COUPLING CIRCUITS

11-1. "Coupling' is defined as the means by which signals are transferred from one circuit to another. Wires, resistors, coils, capacitors, or transformers may be used to perform this function. Coupling may be direct, resistive, inductive, or capacitive.

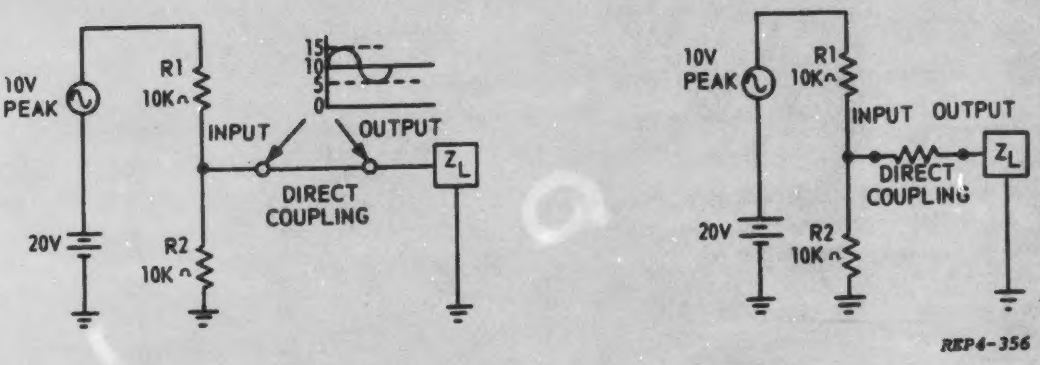
11-2. In this section, we will discuss and analyze direct-coupling, RC-coupling, LC-coupling, and transformer-coupling circuits.

11-3. Direct Coupling

11-4. The first coupling circuit is direct coupling, as shown in figure 11-1. Direct coupling may use a conductor to connect two circuits together; this provides a DIRECT path for signal currents. This type coupling provides an exact reproduction of the input signal at the output of the coupling circuit. This exact reproduction is called "high fidelity," which is desirable. It also couples DC voltages from the input to the output. This has both advantages and disadvantages.

11-5. In place of the wire (figure 11-1A), direct-coupling circuits often use a resistor (figure 11-1B). The coupling resistor is in series with the signal path. The input voltages feed through the resistor to the output circuit. The loading effect of Z_L will cause a decrease in signal amplitude at the coupling network output. Current through the coupling resistor causes a voltage drop which subtracts from the input signal.

11-6. Direct coupling operates over a wide frequency range, beginning at 0 hertz. Recall that frequency does not affect resistance. Direct coupling circuits have no reactive components and are considered "resistive," with no phase shift.



REP4-356

A

B

Figure 11-1

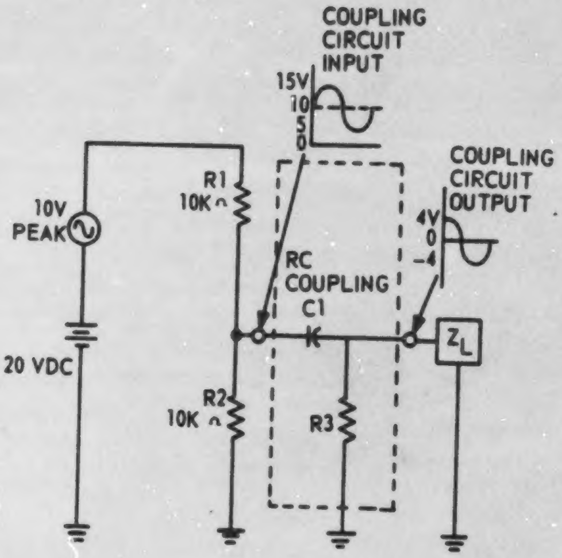


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Figure 11-2

11-7. RC Coupling

11-8. Figure 11-2 shows a typical RC coupling circuit connecting two circuits. The signal applied to Z_L is the voltage developed across the resistor. Observe that the capacitor blocks the passage of DC voltage from one circuit to the other. The input to the coupling circuit is at a 10-volt reference, but the output reference is zero.

11-9. An important consideration in RC-coupled circuits is the relative magnitude and phase between the input and output voltages.

11-10. As has been discussed in preceding lessons, capacitor current leads capacitor voltage by 90°. This means that the signal voltage developed across R3 cannot be in phase with the signal across R2. The voltage across R3 will lead the voltage across R2 by some angle between 0° and 90°. You can see this if you draw C1 and R3 as a series circuit. Use the voltage across R2 as E_a.

11-11. Now, let's consider the effects of frequency on this type of circuit. The higher the frequency, the smaller the reactance of the capacitor, and the more resistive the circuit. When this happens, resistors R2 and R3 can be considered to be in parallel. R1, R2, and R3 act like a series-parallel resistive circuit. The frequency range where C acts as a short becomes the operational frequency range. This is shown in the frequency response curve of an RC-coupling circuit, figure 11-3.

11-12. On the other hand, the lower the frequency, the greater the reactance of C. This causes a smaller portion of the voltage across R2 to appear across R3; and a greater phase difference to exist between E_{R2} and E_{R3}, with E_{R3} leading. As you recall from filter circuits, as the frequency becomes lower, the capacitor acts more like an open. At 0 hertz, the capacitor will completely block the signal and the output drops to zero as shown in figure 11-3.

11-13. The voltage across R3 also drops off at the very high frequencies. If we increase the frequency above point b in figure 11-3, a factor called "stray capacitance" attenuates the signal. Wiring and things like the resistor leads form a capacitance. It is such a low opposition at high frequencies that the signal is greatly attenuated.

11-14. You can see, therefore, that there can be a large change in output voltage and phase when frequency is varied. In practical RC-coupling circuits, the range of frequencies passed is determined by capacitance.

11-15. At frequencies above point "a" the capacitor offers a minimum amount of impedance to

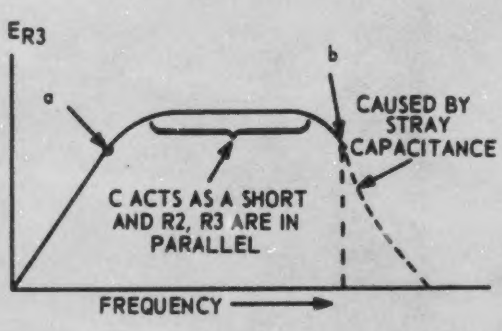

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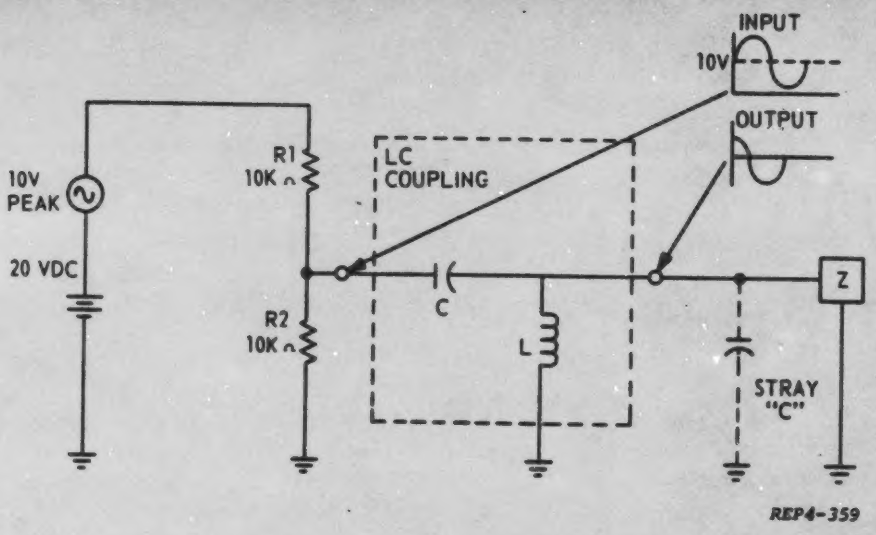
Figure 11-3



REP4-359

Figure 11-4

the signal. The lower frequency limit of the RC-coupling circuit falls where R = X_C and the output equals .707 of the input signal. The upper frequency limit falls at point "b" where the stray capacitance causes the output signal to equal .707 of the input signal.

1-16. LC Coupling

11-17. LC coupling, like RC coupling, is used in circuits with frequencies ranging from audio to RF.

11-18. During the discussions of capacitors and inductors, the relative impedance of these devices at various frequencies was identified. These characteristics are used to explain the action of the LC-coupling circuit.

11-19. Refer to figure 11-4. At very low frequencies X_C is very high and prevents coupling of the signal. As frequency increases, X_C decreases, and X_L increases. This causes the output to increase. At some frequency C and L become series resonant ($X_C = X_L$). The output may then be more than the input, determined by the Q of the coupling circuit. A further increase in frequency causes the output to drop. Going away from resonance, current decreases; therefore, I x X_L decreases.

11-20. At some high frequency the impedance of the capacitor becomes very low; so the capacitor acts as a short and the high reactance of the inductor is effectively in parallel with R2. The voltage output, then, will nearly equal the voltage across the resistor R2.

11-21. Figure 11-5 is a typical response curve of an LC-coupling circuit. Both RC- and LC-coupling circuits are considered "capacitive" coupled circuits. Now, we will discuss inductive coupling.

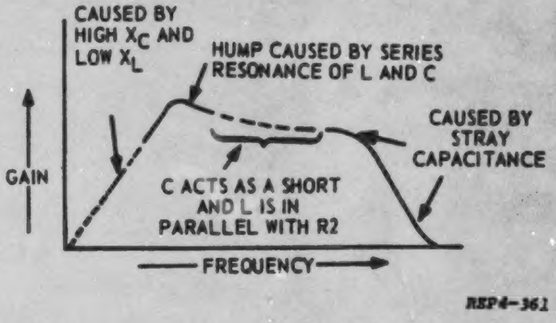


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Figure 11-5

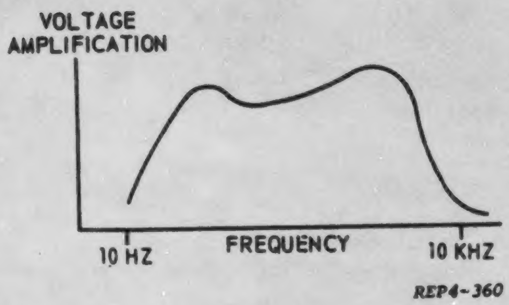


Figure 11-6

11-22. Transformer Coupling

11-23. You studied three types of transformers, power, audio, and RF, in preceding lessons. Of these the audio and RF transofrmers are used in coupling circuits. Coupling transformers consist of two or more coils that couple energy by mutual inductance. Depending on the frequency, a transformer may use an iron, a magnetic alloy, or an air core. The coil connected to the signal source is called the primary winding; the coil connected to the load is called the secondary winding. The main area of concern is why transformers are sometimes used in coupling circuits, rather than RC or LC coupling.

11-24. Transformer coupling has certain characteristics which are not available with other types of coupling circuits. A voltage step-up or step-down can be obtained with a transformer. The two separate windings block DC voltages. Transformer coupling can be used to couple a high impedance source to a low impedance load, or vice versa, by choosing a suitable turns ratio.

11-25. Other characteristics of transformer coupling considered disadvantages are: greater cost, greater shielding requirements and the possibility of poorer frequency response at the higher and lower frequencies. Figure 11-6 shows a typical response curve of an audio transformer.

Chapter 12

THE OSCILLOSCOPE

12-1. The oscilloscope is a test instrument that is capable of a number of functions. First, it can measure voltage; second, it can determine frequencies; third; it can show waveforms. Some oscilloscopes can also display two waveforms at the same time, making comparisons possible. The oscilloscope is commonly referred to as a SCOPE.

12-1. Oscilloscopes vary from the simple to the complex. They are made in a number of sizes by many manufacturers. Therefore, there are many models, but they all have certain elements in common. First, all scopes have a cathode ray tube which has a face, or screen, where waveshapes are displayed.

12-3. Second, controls are provided to adjust the display so voltage, time, and frequency can be determined.

12-4. An important control, and one common to all scopes, is the INTENSITY control. Its proper use gives a good image and prevents burning a hole into the coating on the face.

12-5. The FOCUS control permits the adjustment of the sharpness of the dot, or trace. In addition to this control some scopes may have an ASTIGMATISM control. It insures that all parts of the waveform will be in focus at the same time.

12-6. The HORIZONTAL POSITION control permits the operator to position the dot, or waveshape, to the right or left on the scope face. When used with the VERTICAL POSITION control, which positions the dot up and down, it is possible for the operator to move the dot to any point on the face of the scope.

12-7. A vertical input jack is provided on the front of the scope. The signal to be viewed is normally brought in on the vertical input and goes to the vertical deflection plates. The normal input to the horizontal deflection plates is the sweep voltage from the internal sweep generator. The sweep voltage causes the dot to move from left to right across the screen. As this happens, the signal voltage causes the dot to move up or down as signal amplitude varies, until the dot reaches the right side of the screen. At this time the sweep voltage goes from maximum positive to maximum negative very rapidly, and the dot returns to the left side. The time required or this return is called FLY BACK TIME. See figure 12-1. A horizontal input jack is provided on the front of the oscilloscope for use when the horizontal input signal does not come from the internal generator.

12-8. Scopes come equipped with a direct probe, which connects the oscilloscope to the signal to be viewed. Some scopes are equipped with an attenuator probe. The most commonly used attenuator probe is the 10:1. This reduces the input signal to one tenth of the original value to extend the voltage range of the scope. A 10:1 attenuator probe will reduce a 400 volt input to 40 volts. In this way, the range of the scope is extended.

12-9. A CALIBRATED ATTENUATOR control for vertical deflection, reduces the vertical input signal amplitude. This circuit extends

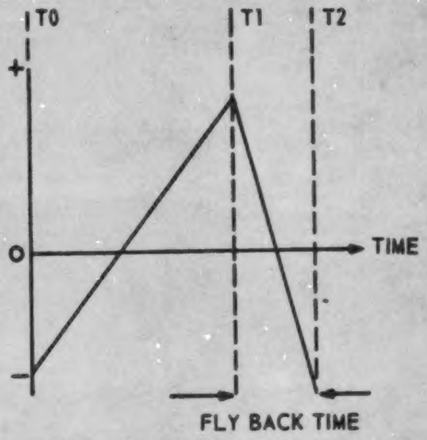


Figure 12-1. Fly Back Time

the range of the scope. Using it, a large input voltage can be reduced and measured. Without it the signal would extend off the scope. Damage to the scope could possibly result. Any voltage applied to the vertical plates will cause the dot to extend up and down in proportion to the voltage applied.

12-10. In addition to vertical deflection, in order to analyze waveshapes, we must have the dot extended into a line across the face of the scope horizontally. For this, the scope has a SWEEP circuit which causes the spot to sweep across the screen. Actually, the dot is first positioned to the left side of the screen, and then, by electrostatic or electromagnetic fields, the dot is moved from left to right. As soon as it reaches the right side, it is quickly moved back to the left to retrace the path just made. When the dot sweeps across the screen, it will appear as a solid line to the eye. The inner surface of the CRT screen is coated with a phosphorescent material which glows for a time after the dot has moved; this is called PERSISTENCE of the screen. The rate of movement can be controlled by horizontal sweep circuits inside the scope. It is the horizontal sweep that must be synchronized with the input waveform to cause the input waveform to appear stationary on the face of the scope. Obviously, the horizontal sweep voltage is applied to the horizontal deflection plates (figure 12-2), and the input waveform is applied to the vertical deflection plates.

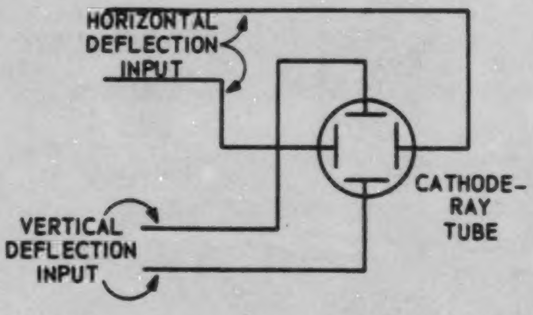
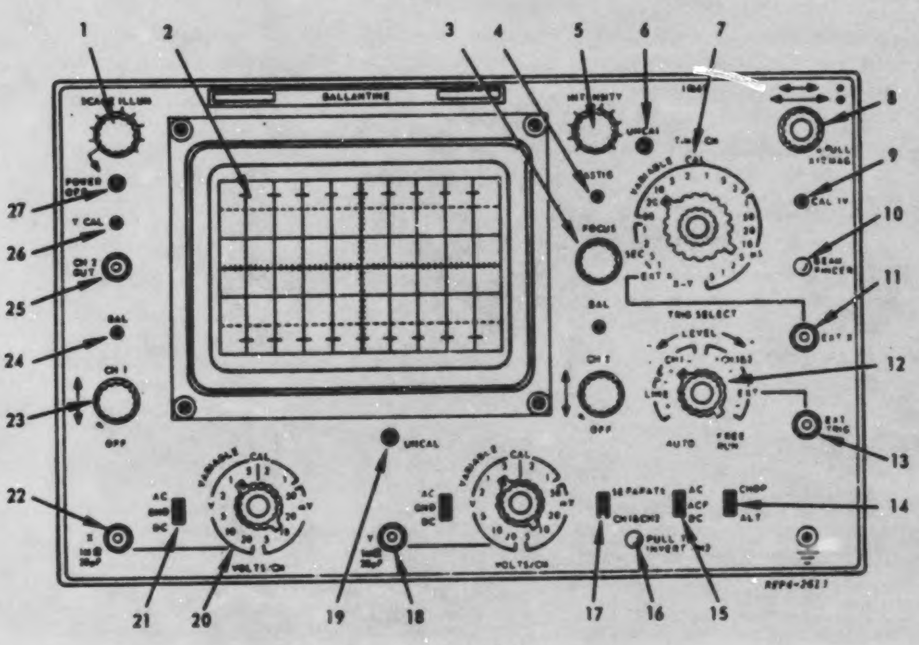

HORIZONTAL
DEFLECTION
INPUT
VERTICAL
DEFLECTION
INPUT
CATHODE-
RAY
TUBE

Figure 12-2. Deflection Inputs

12-11. The oscilloscope you will be using in the Electronic Principles Course is the Ballantine pictured in figure 12-3. The controls are numbered on figure 12-3 and these numbers match the first column call-out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26
27
BALLANTINE
INTENSITY
UNCAL
FOCUS
BAL
CH 1
CH 2
OFF
POWER OFF
V CAL
CAL 1V
TRIG SELECT
LEVEL
AUTO
FREE RUN
EXT TRIG
VARIABLE
CAL
VOLTS/CM
AC
GND
DC
SEPARATE
CH1&CH2
PULL TO INVERT CH2
CHOP
ALT
RFP4-2611

Figure 12-3

numbers of Table 12-1. To help you become familiar with this scope, read the functions of each numbered control as you locate the control on the figure.

Table 12-1 AN/USM-398 Front Panel Controls, Indicators, and Connectors

CALL OUT NUMBER	CONTROL/INDICATOR/ CONNECTOR	FUNCTION
1	SCALE ILLUM	Adjusts brightness of CRT graticule backgroung illumination. Turns power off in POWER OFF detent.
2	CATHODE RAY TUBE	Visually displays signals applied to vertical and horizontal inputs.
3	FOCUS	Adjusts sharpness of display.
4	ASTIG	Adjusts roundness of trace spot.
5	INTENSITY	Controls brightness of display.
6	UNCAL	Lights when TIME/CM VARIBLE control (7) is not in CAL (calibrated) position.
7	TIME/CM (outer knob)	Selects horizontal sweep speed. Determines time required to sweep horizontal one graticule division. When set to EXT X selects horizontal control by external signal applied to EXT X BNC* input jack (11), disabling the internal sweep circuit. When set to X-Y selects horizontal control by external signal applied to channel 1 BNC input jack (marked X) (22).
7	VARIABLE (inner knob)	Provides continuous and overlapping adjustment of sweep speed between calibrated positions of TIME/CM outer knob. Calibrated to TIME/CM position when set fully clockwise to CAL detent position. Must be set in CAL position when measuring time.
8	←→ ○ (outer knob)	Provides coarse adjustment of horizontal position of display.
8	←→ ● (inner knob)	Provides fine adjustment of horizontal position of display.

*BNC is a special connector that permits a connection from one of the input jacks to a banana plug connector.

Table 12-1. AN/USM-398 Front Panel Controls, Indicators, and Connectors (Cont)

CALL OUT NUMBER	CONTROL/INDICATOR CONNECTOR	FUNCTION
8	PULL X10 MAG (inner knob)	In pulled-out position, causes magnification of horizontal sweep or EXT X signal by factor of 10
9	CAL 1V	Test point provides 1-kHz square wave at 1 volt p-p amplitude. May be used for vertical sensitivity calibration and divider probe compensation.
10	BEAM FINDER	Reduces gain of deflection circuits, thus limiting beam deflection to within the CRT graticule. Also operates on blanking amplifier to release sweep retrace blanking. NOTE Make sure INTENSITY control (5) is turned up high enough to make beam visible when using BEAM FINDER, but not too bright so as to burn the coating.
11	EXT X	Connector for an external horizontal input.
12.	TRIG SELECT (outer knob)	Selects source of timebase trigger signal as follows: LINE - Pickoff from ac line voltage, positive or negative slope. CH1 - Pickoff from CH1 vertical amplifier signal, positive or negative slope. CH1 + 2 - Pickoff from the displayed composite vertical deflection signal, positive or negative slope. (Not to be used in CHOP mode.) Use with ACF and DC trigger coupling. EXT - Pickoff from external trigger applied to EXT TRIG jack (13), positive or negative slope. FREE RUN - Sweep recurs at maximum repetition rate and with speed set by the TIME/CM switch.

Table 12-1. AN/USM-398 Front Panel Controls, Indicators, and Connectors (Cont)

CALL OUT NUMBER	CONTROL/INDICATOR/ CONNECTOR	FUNCTION
12	LEVEL (inner knob)	Selects point on amplitude of trigger signal that starts sweep. In AUTO position, sweep synchronizing triggers are produced automatically when signal exceeds 40-Hz repetition rate and exceeds minimum level. In absence of trigger signals, sweep runs free to produce bright line.
13	EXT TRIG	Connector for external trigger signal.
14	CHOP-ALT switch	Selects display switching mode for dual trace vertical deflection. ALT - CH1 and CH2 alternate with each sweep. Used for normal dual trace displays CHOP - CH1 and CH2 alternate at 400 kHz. Used only when comparing signals on long time bases (slower than 1ms/cm). Never used with CH1 & 2 trigger selection, Never used with timebase sweeps faster than 1 ms/cm.
15	AC-ACF-DC (Trigger Coupling)	Selects capacitive or direct coupling of trigger signal. Direct coupling (DC) is normally used for slow or erratic sync signals. Capacitive coupling (AC) blocks DC component but attenuates signals below 50 Hz. Fast capacitive coupling (ACF) attenuates signals below 50 kHz and is used to block unwanted low frequency components of the trigger signals.
16	PULL TO INVERT CH2	Selects polarity for CH2 display. In pulled out position inverts CH2 polarity.
17	SEPARATE - CH1 & CH2	Selects mode for display of vertical deflection channels, separate or added.
18	Y (CH2 input)	Connector for CH2 vertical input signal.
19	UNCAL	Lights when either VOLTS/CM VARIABLE control (20) is not in CAL position.

Table 12-1. AN/USM-398 Front Panel Controls, Indicators, and Connectors (Cont)

CALL OUT NUMBER	CONTROL/INDICATOR/ CONNECTOR	FUNCTION
20	CH1 VOLTS/CM (outer knob)	Selects channel 1 vertical deflection factor for calibrated measurements.
20	CH1 VARIABLE (inner knob)	Provides continuous uncalibrated adjustments between calibrated positins of outer knob. Must be set to CAL position when measuring voltage.
21	CH1 AC-GND-DC (input Coupling)	Set to AC when applying an AC signal or DC when applying a DC signal. GND grounds out either signal to enable operator to establish a reference line.
22	X (CH1 input)	Connector for CH1 vertical input signal and for horizontal input signal when TIME/CM switch (7) is set to X-Y position.
23	CH1 ↕	Adjusts vertical position of CH1 display. Switches CH1 off when in OFF detent.
24	BAL	Adjusts to minimize vertical position change when rotating volts/cm switch.
25	CH2 OUT	Connector for output of CH2 vertical amplifier signal.
26	Y CAL	Provides adjustment of vertical sensitivity for both channels.
27	Power	Lights when operating line power is applied.
	Probe trimmer screw adjustment (not shown)	Adjusts frequency compensation of attenuator probe.

12-12. To effectively use the oscilloscope, it is necessary to have a more complete understanding of the function of certain controls and accessories.

12-13. TIME/CM Control

12-14. The time it will take the electron to travel across the scope is determined by the TIME/CM control. The control is divided into three areas of time from 1 second to .5 microseconds.

12-15. The CRT scale is divided into 10 horizontal divisions that are 1 centimeter apart. If the TIME/CM control were set to the 1 microsecond position, the sweep would move 1 centimeter in 1 microsecond, or completely across the scale in 10 microseconds. If an AC signal on the scale shows that 1 cycle is 7 centimeters long and the TIME/CM control is set to 5 microseconds, the time for one cycle would then be 35 microseconds. A horizontal scale permits signals to be measured in tenths of a centimeter. If one cycle is 7.4 centimeters and the TIME/CM control is set to 5 microsecond, the time for one cycle is 37.0 microseconds.

12-16. VOLTS/CM Control

12-17. The input signal is fed to the VOLTS/CM control. This front panel control steps down the amplitude of the input voltage. This control is related to the vertical scale on the face of the cathode ray tube. The scale is divided into six one centimeter divisions and it is used to measure amplitude. The VOLTS/CM control is calibrated in ranges from 5 millivolts to 20 volts per division. Therefore, if the amplitude of the signal is six divisions and the VOLTS/CM control is set to 20, the peak-to-peak amplitude would be 6 x 20 or 120 volts. This is the maximum voltage that can be measured by this scope without using an external attenuator.

12-18. Attenuator Probe.

12-19. To obtain an accurate signal representation on the scope, shielded cables must be used to reduce the amount of magnetic or electric coupling of the leads. These leads are normally made from flexible coaxial cable.

12-20. The purpose of the attenuator probe is to prevent the circuit under test from being loaded down, resulting in distortion of the signal. The probe does divide the input signal voltage by a 10:1 ratio. Therefore, 10 volts input would be measured on the oscilloscope as only 1 volt when the attenuator probe is used.

12-21. Measurement of Time.

12-22. The measurement of time is accomplished using the horizontal scale of the graticule. Figure 12-4 shows one cycle of an AC sine wave extending the full 10 centimeters of the graticule. If you wish to measure the time of one alternation, count the number of centimeters for one-half cycle, and here we find it to be 5. By multiplying 5 centimeters by the setting of the TIME/CM control, we can calculate the time for one alternation. Assume that the TIME/CM control is set to 20 microseconds. This would be 5 centimeters times 20 microseconds which equals 100 microseconds for one alternation. The time for one complete cycle would be 10 centimeters times 20 microseconds = 200 microseconds. Remember, the time indicated by the setting of the TIME/CM control is the time it takes the dot to travel one centimeter across the scale.

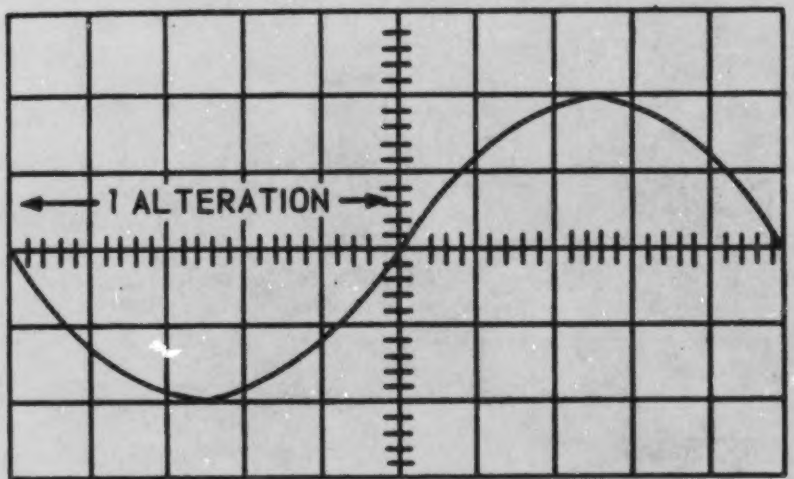

Figure 12-4

12-23. Calculating Frequency.

12-24. Now that you can measure sweeptime, it is very easy to calculate the frequency of the AC signal. The formula used is:

$$\text{Frequency} = \frac{1}{\text{Time}}$$

12-25. When determining frequency, you must always determine the time for one cycle. In the preceding example, the time for one cycle is 200 microseconds. Inserting this into the formula, we find:

$$f = \frac{1}{200 \times 10^{-6}}$$

$$f = 5\ \text{kHz}$$

12-26. When setting up the oscilloscope to measure an unknown frequency, you should obtain as near one cycle across the scale as possible by using the TIME/CM control. You must also insure that the VARIABLE TIME/CM control is in the CAL position or your reading will not be accurate. Figure 12-5 shows an AC Signal on the scope that is 6.8 centimeters for one complete cycle. If the TIME/CM control is set to 5 microseconds, the time for one cycle would be:

6.8 centimeters x 5 microseconds = 34 microseconds

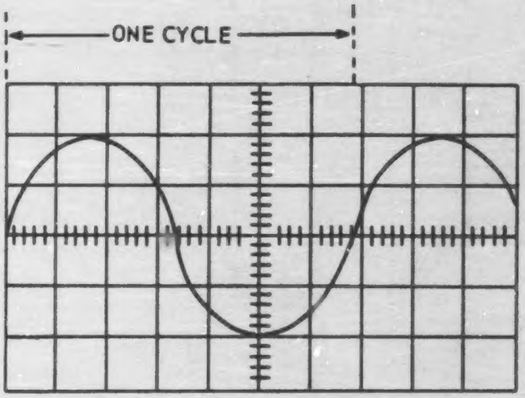

Figure 12-5

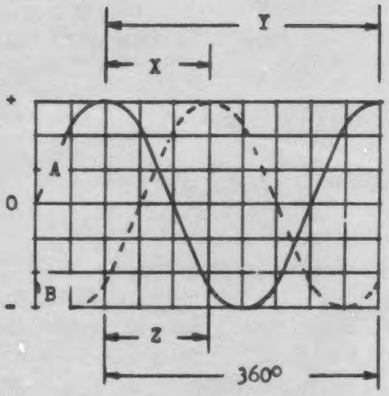

Figure 12-6

12-27. Applying the time for one cycle to the formula:

$$f = \frac{1}{t} = \frac{1}{34 \times 10^{-6}} = 29{,}411\ \text{Hz}$$

12-28. Measurement of Phase

12-29. The dual-trace capability of the oscilloscope is very useful for measuring phase difference of two sine waves having the same frequency. Figure 12-6 shows the two sine waves being displayed on the oscilloscope. One waveform is positioned directly over the other (superimposed) so the difference in phase is easy to see. This is shown as distance X and equals 3 centimeters. X also represents the unknown phase angle. One complete sine wave is distance Y and equals 8 centimeters.

Distance Y also represents 360 degrees (one complete sine wave).

Dividing 360 degrees by 8 centimeters results in each centimeter equalling 45 degrees.

$$\frac{360\ \text{degrees}}{8\ \text{cm}} = 45\ \text{degrees per centimeter}$$

Multiplying the 3 centimeters difference in the waves by the 45 degrees per centimeter results in a phase difference of 135 degrees.

3 cm x 45 degrees/cm = 135 degrees

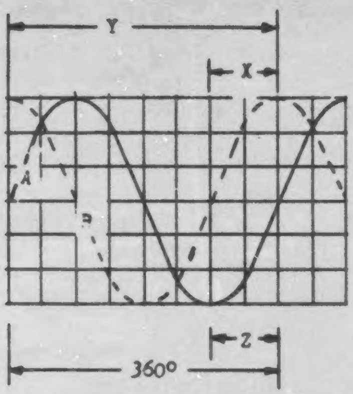

Figure 12-7

12-30. Lets try another example. See figure 12-7. Here the phase is different but, the procedure is the same. There are two centimeters difference between the two waves. Two centimeters x 45 degrees/cm = 90 degrees. This gives the phase difference between the two signals. Notice the distances were all measured from like points on the sine waves. Y is measured between the points where sine wave A corsses the zero reference line and starts positive. X is measured between the zero crossing of sine wave B and sine wave A, where they start going positive. Also notice that wave A crosses zero after wave B has crossed zero. Sine wave A lags sine wave B by 90 degrees.

12-31. Amplitude Measurement.

12-32. In measuring voltages with the scope, it must be kept in mind that it measures the PEAK-TO-PEAK value. If the signal is a sine wave, the peak-to-paek value may be converted to the RMS or EFFECTIVE value by multiplying the peak-to-peak value by .3535.

EXAMPLE: If the peak-to-peak value is 200 volts, the effective value is 200 x .3535 or 70.7 volts.

12-33. The graticule scale on the face of the CRT is used for measuring voltage amplitude. When an AC signal is observed on the scope, a quick calculation can be made to determine its peak-to-peak voltage amplitude.

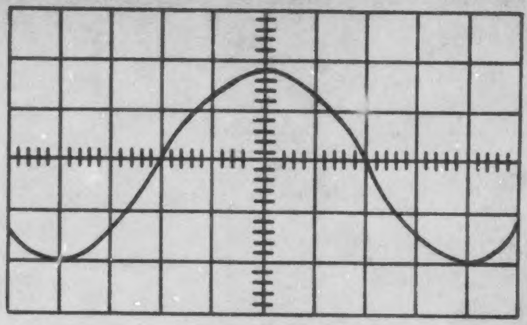

Figure 12-8

Refer to figure 12-8. This shows an AC signal 3.8 centimeters in amplitude peak-to-peak. When checking the VARIABLE VOLTS/CM control, we find it is in the CAL position and the VOLTS/CM control is set on 10. You can calculate 3.8 centimeters x 10 volts/cm = 38 volts peak-to-peak. When reading sinusoidal voltages, we normally use a meter which shows effective voltage. In order to convert from peak-to-peak to effective voltage, use the following formula.

Peak-to-peak x .3535 = Effective

12-34. Therefore, if you were reading 38 volts peak-to-peak, insert it into the formula as follows:

38 x .3535 = 13.433 Effective Volts

12-35. You should keep in mind that the highest range of the VOLTS/CM control is 20, and there are only six divisions vertically on the scale. Therefore, the peak-to-peak voltage that you can measure in the CAL position is 120 volts.

12-36. Measurement of DC Voltage

12-37. To measure a DC voltage ground the input probe to the oscilloscope and move the trace down to the bottom line of the scale by using the Vertical Positioning control. Figure 12-9 shows the measurement of DC voltage. After establishing a ground reference, the probe is placed on the DC voltage to be measured. The trace moved up to point B or 4.4 centimeters. If the

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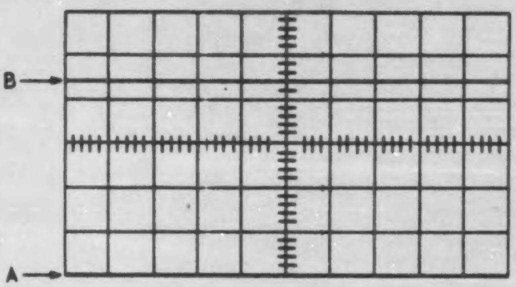

Figure 12-9

VOLTS/CM control was set to 10, the DC voltage shown on the scale would be 44 volts. If the trace had moved down, it would indicate the presence of a negative DC voltage and the ground reference would have to be set at the top of the scale. Again, the maximum voltage that can be measured directly is 20 volts per division, or 120 volts. Higher voltages can be measured if an external attenuator is used at the input jack.

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Prepared by Keesler TTC
KEP-GP-20

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 20

OSCILLOSCOPE USES

JANUARY 1976

AIR TRAINING COMMAND

7-7

Designed For ATC Course Use

DO NOT USE ON THE JOB

Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-1
KEP-GP-20
January 1976

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 20

OSCILLOSCOPE USES

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

Title — Page
Overview — 1
List of Resource — 1
Adjunct Guide — 1

Laboratory Exercises:

20-1 — 2
20-2 — 9
20-3 — 10
20-4 — 11
Module Self-Check — 13
Answers — 16

OVERVIEW

1. SCOPE: The oscilloscope is a test instrument that can be used to measure voltage or time and show waveforms. Oscilloscopes vary from simple to complex. Some can display two or more waveforms at the same time. This module provides an introduction, detailed operating procedures, and practical training for a dual-trace general-purpose oscilloscope.

2. OBJECTIVES: Upon completion of this module, you should be able to satisfy the following objectives:

a. Given an oscilloscope, trainer, and formulas, measure the time and calculate the frequency of an AC voltage within ±10 percent accuracy.

b. Given a dual trace oscilloscope and trainer, determine within ±10 percent accuracy the phase relationship by comparing two signals of the same frequency.

c. Given an oscilloscope and trainer, measure the amplitude of DC and AC voltages ±10 percent accuracy.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text

Supersedes KEP-GP-20, 1 July 1974.

AUDIO-VISUALS:

Television Lesson, Use of Oscilloscope, TVK 30-212A

Television Lesson, Frequency and Phase Meas., TVK 30-212B

(NOTE: These lessons refer to a different oscilloscope, but the controls are basically the same as on the scope you will use.)

LABORATORY EXERCISES:

Introduction to the Oscilloscope 20-1

Frequency Measurements 20-2

Phase Measurements 20-3

Voltage Measurements 20-4

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK. IF NOT, SELECT ONE OF THE RESOURCES AND BEGIN STUDY.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers in the back of this guidance package.

If you experience any difficulty, contact your instructor.

Begin the program.

A. Turn to Student Text, Volume III, and read paragraphs 12-1 through 12-20. Return to this page and answer the following questions.

1. Which is NOT a common use of the scope?

_____ a. Measure voltage.

_____ b. Measure current.

_____ c. Measure frequency.

_____ d. Display waveforms.

2. Intensity of the trace should be:

_____ a. High at all times so that the waveshape can easily be seen.

_____ b. No higher than is necessary to clearly see the waveshape.

_____ c. At whatever brightness the operator chooses.

_____ d. Adjusted by centering the intensity control at all times, regardless of brightness.

3. One element that all scopes have in common is:

_____ a. The cathode ray tube.

_____ b. Electromagnetic deflection.

_____ c. An attenuator probe.

_____ d. Capability of displaying two waveforms simultaneously.

CONFIRM YOUR ANSWERS

B. Turn to Laboratory Exercise 20-1. This exercise will familiarize you with the controls of the scope and provide you with practice in the use of these controls. Return and continue with this program upon completion of the exercise.

C. Turn to Student Text, Volume III, and read paragraphs 12-21 through 12-30. Return to this page and answer the following questions.

1. Find the frequency of a signal if one cycle is 2.5 cm long on the scope and the TIME/CM control is set on 2 mS. __________

2. If a signal of 1000 Hz is displayed on the scope and TIME/CM control is set on:

a. .1 mS

b. .2 mS

c. .5 mS

What will be the length of one cycle in cm?

a. ______________________________

b. ______________________________

c. ______________________________

3. If the phase difference between two signals is 0.5 cm and the length of one cycle is 8 cm, then the phase difference is: ____________________ degrees.

CONFIRM YOUR ANSWERS

D. Turn to Laboratory Exercise 20-2 and 20-3 in which you will actually use the scope to make frequency and phase measurements. Return and continue with this program upon completion of the exercise.

E. Turn to Student Text, Volume III, and read paragraphs 12-31 through 12-37. Return to this page and answer the following questions.

1. What is the peak-to-peak amplitude of a signal that is 3.5 cm in height on the scope with the VOLTS/CM control set on 2V?

____

2. What is the effective voltage of a signal if it is 4 cm high on the scope and the VOLTS/CM control is set on 5V?

____

3. How many cm in height will a 10 VAC signal be if the VOLTS/CM control is set on 10V?

____

CONFIRM YOUR ANSWERS

F. Turn to Laboratory Exercise 20-4. In this exercise you will practice using the scope to measure voltage.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

LABORATORY EXERCISE 20-1

Introduction to the Oscilloscope

OBJECTIVES:

1. Match each control with its function when gven a list of oscilloscope controls and a list of their functions.

2. When given a diagram of the front panel of the oscilloscope, locate and label the controls while observing an actual scope and a list of its controls.

3. Locate and demonstrate the use of the oscilloscope controls needed to properly display one cycle of a sine wave, centered on the scope with a vertical size of 4 centimeters and a horizontal size of 10 centimeters.

EQUIPMENT;

Oscilloscope, AN/USM-398
Sine-Square Wave Generator 4864

REFERENCES:

Student Text Volume III, paragraphs 12-1 through 12-20.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

A. Read the list of objectives given for this exercise. Keep in mind that the exercise is designed to guide you through certain steps so that you will be able to do each of the objectives. The objectives will be accomplished one at a time.

1. Read table 1-1 and locate each control on the oscilloscope.

Table 1-1. AN/USM-398 Front Panel Controls, Indicators and Connectors

CALL OUT NUMBER	CONTROL/INDICATOR/ CONNECTOR	FUNCTION
1	SCALE ILLUM	Adjusts brightness of CRT graticule background illumination. Turns power off in POWER OFF detent.
2	CATHODE RAY TUBE	Visually displays signals applied to vertical and horizontal amplifiers.
3	FOCUS	Adjusts sharpness of display.
4	ASTIG	Adjusts roundness of trace spot.
5	INTENSITY	Controls brightness of display.
6	UNCAL	Lights when TIME/CM VARIABLE control (7) is not in CAL position.
7	TIME/CM (outer knob)	Selects horizontal sweep speed. Determines time required to sweep horizontal one graticule division. By pulling PULL X10 MAG knob (8), display can be expanded by 18, increasing fastest sweep to 50 ns/cm.
		When set to EXT X selects horizontal control by external signal applied to EXT X BNC input jack (11).
		When set to X-Y selects horizontal control by external signal applied to channel 1 BNC input jack (marked X) (22).
	VARIABLE (inner knob)	Provides continuous and overlapping adjustment of sweep speed between calibrated positions of TIME/CM outer knob. Calibrated to TIME/CM position when set fully clockwise to CAL detent position. Turned counterclockwise, sweep speed decreases; however, TIME/CM readings are uncalibrated.
8	⟷ (outer knob)	Provides coarse adjustment of horizontal position of display.
8	↔ (inner knob)	Provides fine adjustment of horizontal position of display.
8	PULL X10 MAG (inner knob)	In pulled-out position, causes magnification of horizontal sweep or EXT X signal by factor of 10.

Table 1-1. Oscilloscope Controls and Functions (Continued)

CALLOUT NUMBER	CONTROL/INDICATOR CONNECTOR	FUNCTION
9	CAL 1V	Test point provides 1-kHz square wave at 1 volt p-p amplitude. May be used for vertical sensitivity calibration and divider probe compensation.
10	BEAM FINDER	Reduces gain of deflection amplifiers, thus limiting beam deflection to within the CRT graticule. Also operates on blanking amplifier to release sweep retrace blanking. NOTE Make sure INTENSITY control (5) is turned up high enough to make beam visible when using BEAM FINDER.
11	EXT X	Connector for an external horizontal input.
12	TRIG SELECT (outer knob)	Selects source of timebase trigger signal as follows: LINE - Pickoff from AC line voltage, positive or negative slope. CH1 - Pickoff from CH1 vertical amplifier signal, positive or negative slope. CH1 & 2 - Pickoff from the displayed composite vertical deflection signal, positive or negative slope. (Not to be used in CHOP mode.) Use with ACF and DC trigger coupling. EXT - Pickoff from external trigger applied to EXT TRIG jack (13), positive or negative slope. FREE RUN - Sweep recurs at maximum repetition rate and with speed set by the TIME/CM switch.

Table 1-1. AN/USM-398 Front Panel Controls, Indicators, and Connectors (Continued)

CALL OUT NUMBER	CONTROL/INDICATOR/ CONNECTOR	FUNCTION
12	LEVEL (inner knob)	Selects point on amplitude of trigger signal that starts sweep. In AUTO position, sweep synchronizing triggers are produced automatically when signal exceeds 40-Hz repetition rate and exceeds minimum level. In absence of trigger signals, sweep runs free to produce bright line.
13	EXT TRIG	Connector for external trigger signal.
14	CHOP-ALT switch	Selects display switching mode for dual trace vertical dflection. ALT - CH1 and CH2 alternate with each sweep. Used for normal dual trace displays. CHOP - CH1 and CH2 alternate at 400 kHz. Used only when comparing signals on long time bases (slower than 1 ms/cm). Never used with CH1 & 2 trigger selection. Never used with timebase sweeps faster than 1 ms/cm.
15	AC-ACF-DC (Trigger Coupling)	Selects capacitive or direct coupling of trigger signal. Direct coupling (DC) is normally used for slow or erratic sync signals. Capacitive coupling (AC) blocks DC component but attenuates signals below 50 Hz. Fast capacitive coupling (ACF) attenuates signals below 50 kHz and is used to block unwanted low frequency components of the trigger signals.
16	PULL TO INVERT CH2	Selects polarity for CH2 display. In pulled out position inverts CH2 polarity.
17	SEPARATE - CH1 & CH2	Selects mode for display of vertical deflection channels, separate or added.
18	Y (CH2 input)	Connector for CH2 vertical input signal.

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Table 1-1. AN/USM-398 Front Panel Controls, Indicators, and Connectors (cont)

CALLOUT NUMBER	CONTROL/INDICATOR/ CONNECTOR	FUNCTION
19	UNCAL	Lights when either VOLTS/CM VARIABLE control (20) is not in CAL position.
20	CH1 VOLTS/CM (outer knob)	Selects channel 1 vertical deflection factor for calibrated measurements.
20	CH1 VARIABLE (inner knob)	Provides continuous uncalibrated adjustments between calibrated positions of outer knob. Calibrated to VOLTS/CM positions when set fully clockwise to CAL detent position.
21	CH1 AC-GND-DC (Input Coupling)	Selects capacitive (AC) or direct (DC) coupling of input signal; or grounds (GND) the amplifier stages and disconnects the input to establish display reference of ground on the CRT graticule.
22	X (CH1 input)	Connector for CH1 vertical input signal and for horizontal input signal when TIME/CM switch (7) is set to X-Y position.
23	CH1	Adjusts vertical position of CH1 display. Switches CH1 off when in OFF detent.
24	BAL	Adjusts to minimize vertical position change when rotating volts/cm switch.
25	CH2 OUT	Connector for output of CH2 vertical amplifier signal.
26	Y CAL	Provides adjustment of vertical sensitivity for both channels.
27	Power	Lights when operating line power is applied.
	Probe trimmer screw adjustment (not shown)	Adjusts frequency compensation of attenuator probe.

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2. Match each conhcol with is function by placing the number representing the function next to the letter of the control.

______ a. FOCUS

______ b. VARIABLE TIME/CM (Red)

______ c. TIME/CM   1 input signal.

______ d. ←→ (outer knob)

______ e. PULL TO INVERT CH2

______ f. POWER AND SCALE ILLUM

______ g. ↕ CH 1

______ h. VOLTS/CM (Channel 1)

______ i. VARIABLE VOLTS/CM (Red) (channel 1)

______ j. INTENSITY

1. Adjusts for the desired brightness of the CRT trace.

2. Selects vertical deflection factor of Channel

3. Applies power to the instrument and controls illumination of the graticule.

4. Provides coarse adjustment of horizontal position of the display.

5. Adjusts sharpness of display.

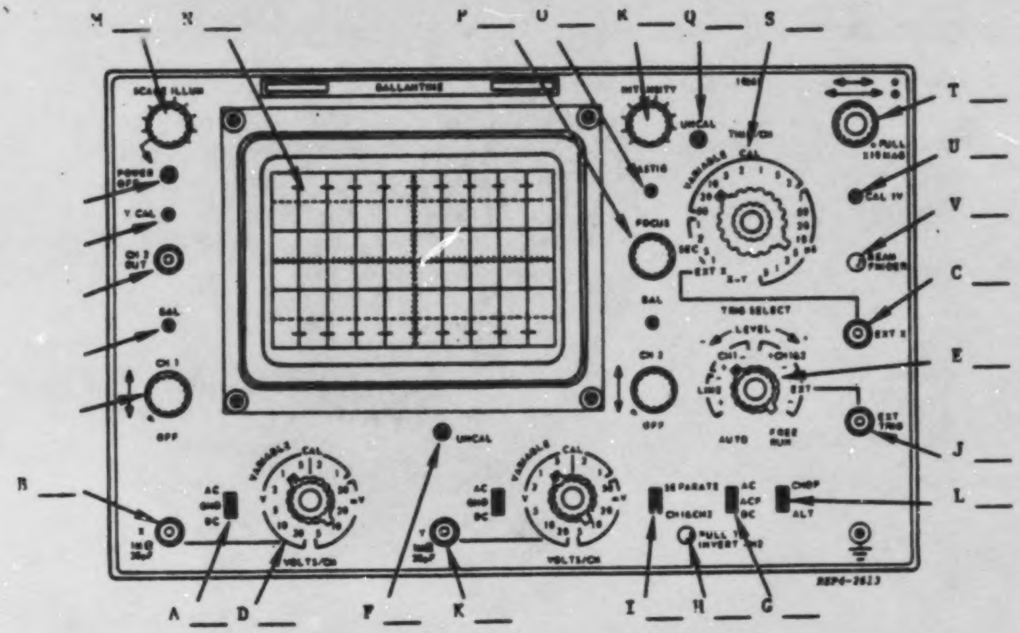
6. Normally set to CAL, but provides intermediate adjustment between the settings of the CH1 VOLTS/CM switch.

7. Controls the location of the CRT trace (channel 1) with respect to the Y axis. Switches CH1 OFF when in the OFF detent.

8. Selects polarity for CH 2 display.

9. Selects desired sweep speed.

10. Normally set to CAL, but provides intermediate adjustment of sweep rates between settings of the TIME/CM switch.


M
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BALLANTINE
SCALE ILLUM
POWER OFF
Y CAL
CH 2 OUT
BAL
CH 1
OFF
INTENSITY
UNCAL
FOCUS
BAL
CH 2
OFF
TIME/CM
CAL
VARIABLE
TRIG SELECT
LEVEL
AUTO
FREE RUN
EXT X
EXT TRIG
CAL 1V
BEAM FINDER
AC
GND
DC
VOLTS/CM
UNCAL
SEPARATE
CH1&CH2
PULL TO INVERT CH2
CHOP
ALT

Figure 1-1. AN/USM-398 Front Panel Controls, Indicators, and Connectors

3. Using table 1-1 and the actual oscilloscope, locate each control and fill in the CALL OUT number on figure 1-1.

CONFIRM YOUR ANSWERS

B. Now you are going to operate the scope and display a waveform on the CRT.

1. Prepare the oscilloscope by making these control settings.

CONTROL	SETTING
CH1 AC-GND-DC	AC
Scale ILLUM/POWER	ON
INTENSITY	midposition

2. Find the trace by pressing the BEAM FINDER and then turning the ↕ CH1 and ←→ controls to bring the trace to the center of the CRT.

3. Adjust intensity to suit your individual eye comfort, but be careful not to "burn" the face of the CRT with too much intensity.

4. Complete the oscilloscope preparation by setting the following controls:

CONTROL	SETTING
CH2 ↕	OFF
←→	Set this control so that the trace originates on the first vertical line on the left.
TIME/CM	Set on 0.1 mS.
LEVEL (red)	Set for AUTO.
TRIG SELECT	Set for CH 1 +.
VOLTS/CM, CH1	Set for 10V.
CH1 ↕	Set this control so that the trace is located on the center horizontal line of the scale.

NOTE: At this tme there should be a stable trace across the scope, extending from the left vertical line across the entire scale and lying on the center horizontal line; IF NOT, CALL YOU INSTRUCTOR FOR ASSISTANCE.

CONTROL	SETTING
POWER Switch	ON
SINE WAVE AMPLITUDE	MAX
RANGE	10V
FREQ. MULTIPLIER	10
FREQUENCY (CPS)	100

6. Connect a lead between the ground post on the scope and the signal generator. Connect the oscilloscope CH 1 (X) input to the signal generator sine wave output jack (red).

NOTE: There should now be a sine wave displayed on the scope. It should be approximately 10 cm in length and 3 cm in height.

7. Adjust the VARIABLE VOLTS/CM control. This control

_____ a. Changes vertical size.

_____ b. Changes horizontal size.

8. Adjust the VARIABLE VOLTS/CM for a sine wave that is 3 cm in height. It may be necessary to change the VOLTS/CM switch to another setting.

9. Adjust the VARIABLE TIME/CM control fully CW and then fully CCW. This causes one cycle of the waveform to:

_____ a. Increase and decrease in horizontal size.

_____ b. Increase and decrease in vertical size.

10. Adjust the VARIABLE TIME/CM control until one sine wave is 10 cm long.
CONFIRM YOUR ANSWERS

LABORATORY EXERCISE 20-2

Frequency Measurements

OBJECTIVE:

Using the dual trace oscilloscope, trainer, and formulas, determine within 10 percent accuracy the frequency and time of an AC signal.

EQUIPMENT:

Oscilloscope, Ballantine, AN/USM-398
Sine-Square Wave Generator 4864
AC Inductor and Capacitor Trainer 5967

REFERENCE:

Student Text, Volume III, paragraphs 12-2 through 12-27

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

1. Prepare the scope to display a waveform on CH1.

2. Set up the generator for an output of 10 V AC, at a frequency of 100 Hz.

3. Connect the sine wave output from the generator to the oscilloscope CH 1 (X) input.

4. Adjust the scope to display one cycle 10 cm long and 4 cm in height (peak to peak).

5. Have the instructor change the frequency of the generator to a value unknown to you.

6. Observe the scope display. Has the frequency increased or decreased?

7. Set the VARIABLE TIME/CM control to CAL.

8. With the TIMF/CM control, make one cycle of the waveform as close to 10 cm as possible, but not any more than 10 cm.

9. How many cm are there per cycle?

10. Using the formula "TIME of Cycle = Number of cm x TIME/CM setting," solve for the time of one cycle.

TIME = ______________________ sec.

11. Using the time of one cycle and the formula f = 1/t, solve for frequency.

f = ______________________

CONFIRM YOUR ANSWERS

LABORATORY EXERCISE 20-3

Phase Measurements

OBJECTIVE:

Using the dual trace oscilloscope, trainer and formulas, determine within 10 percent accuracy the phase angle between two AC signals of the same frequency.

EQUIPMENT:

Oscilloscope, Ballantine, AN/USM-398

Sine-Square Wave Generator 4864

AC Inductor and Capacitor Trainer 5967

REFERENCE:

Student Text, Volume III, paragraphs 12-28 through 12-30.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

1. Ground the sine wave generator to the oscilloscope. Connect the "CH 1" probe to the output jack of the sine wave generator. Adjust the size of the sine wave to 3 cm in height and position it in the top half of the graticule.

2. Make these scope control settings:

CONTROL	SETTING
CH 2 AC-GND-DC	AC
CHOP-ALT	ALT
↕ (CH 2 Vertical)	So that CH2 trace is in lower half of the graticule.
TRIG SELECT	EXT +

3. Make these settings on the generator:

CONTROL	SETTING
FREQUENCY	300 Hz
SINE-WAVE AMPLITUDE	Fully CW
RANGE	10V

4. Connect a lead from the EXT TRIG jack on the scope to the CH2 (Y) jack using a BNC connector.

5. Connect a wire from the CH 2(Y) input to the output jack of the sine wave generator. There should now be a stable display.

6. Set the CH2 display to 3 cm in height. What controls are used to make this adjustment?______________________

7. Set the length of the sine wave CH1 and CH2 to exactly 8 cm. What control makes this adjustment?______________________

8. Position the CH1 signal over the CH2 signal. Adjust the VARIABLE VOLTS/CM controls so that each signal is exactly 3 cm high.

9. What phase relationship is now indicated by the display? ____________________

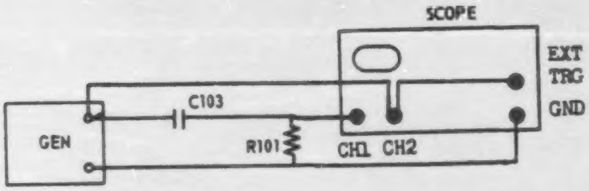


Figure 1-1

10. Using the trainer, construct the circuit shown in figure 1-1.

11. The RC network will cause the CH1 waveform to (lead)(lag) the CH2 waveform.

12. Adjust the CH1 and CH2 VOLTS/CM and VARIABLE controls until the two signals are 6 cm in amplitude and appear somewhat like figure 1-2.

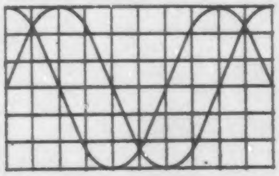


Figure 1-2

13. The distance between the like points on the CH1 and CH2 waveform on the oscilloscope is ____________ cm.

14. The length of one cycle of the CH2 waveform is ____________ cm.

15. Determine the phase difference between the two waveforms using the equation:

$$\frac{\text{Phase Difference}}{} = \frac{\text{Distance between waves}}{\text{Length of one cycle}} \times 360^\circ$$

16. The phase difference is ____________ degrees.

CONFIRM YOUR ANSWERS

CONSULT YOUR INSTRUCTOR FOR THE PROGRESS CHECK.
RETURN TO THE RESOURCE FROM WHICH YOU CAME AND CONTINUE WITH THAT PROGRAM.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

LABORATORY EXERCISE 20-4

Oscilloscope Voltage Measurements

OBJECTIVES:

Using the oscilloscope, measure the amplitude of an AC voltage and the amplitude of a DC voltage.

EQUIPMENT:

Oscilloscope, Ballantine, AN/USM-398

Sine-Square Wave Generator 4864

DC Power Supply 4649

Multimeter PSM-6

REFERENCES:

Student Text, Volume III, paragraphs 12-31 through 12-37.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

A. Measuring an AC voltage.

1. Set up the scope.

CONTROL	SETTING
POWER	ON
VOLTS/CM CH1 (X)	1V
TRIG SELECT	CH 1 +
LEVEL (Red)	AUTO

CONTROL	SETTING
AC-GND-DC CH1	AC
TIME/CM	.5 mS
CH 2 (Y)	OFF

2. Calibrate CH 1

a. Connect a lead from the CAL 1 V output jack to the CH1 input jack.

b. Adjust the VARIABLE VOLTS/CM until the square wave on the scope is exactly 1 cm in amplitude.

c. How many volts per cm are now displayed on the scope? ________

IMPORTANT: THE VARIABLE CONTROL MUST NOT BE MOVED FROM THIS SETTING.

d. Move the CH1 VOLTS/CM control to .5V.

(1) How many cm in height is the square wave? ________

(2) How many volts are there in each cm? ________

(3) What is the peak to peak amplitude of the square wave? ________

e. Move the VOLTS/CM control to 2V.

(1) How many cm in height is the square wave? ________

(2) How many volts are there in each cm? ________

(3) What is the peak amplitude of the square wave? ________

(4) Remove the end of the lead from the CAL 1 V output jack.

3. Set up the signal generator for a 1 kHz, 3V output sine wave. Use the PSM-6 to measure this voltage. The PSM-6 should remain connected to the output of the generator for steps 4 through 8.

4. Ground the signal generator to the oscilloscope.

5. Connect this signal into the CH 1 (X) input of the scope.

6. Position the display for ease of reading the peak to peak amplitude.

a. The signal is ________ cm peak to peak.

b. The peak to peak voltage amplitude of the sine wave is ________.

c. Calculate the effective voltage value of this sine wave ________

d. The difference in the PSM-6 reading and the calculated effective voltage value above was ________.

7. Increase the signal generator output to 10 volts as measured by the PSM-6.

8. Make the necessary position and VOLTS/CM adjustments to display the sine wave within the graticule and yet be easy to measure.

a. What is the number of cms peak to peak? ________.

b. Peak to peak voltage is ________.

c. Effective voltage is ________.

9. Disconnect the signal generator.

CONFIRM YOUR ANSWERS

B. Measuring DC Voltage.

1. Set the DC Power Supply up for a 10-volt reading on its output meter.

2. Set the CH 1 AC-GND-DC control to DC.

3. Position the scope trace on the bottom horizontal line.

4. Ground the black jack of the power supply to the oscilloscope.

5. Set the VOLTS/CM to 2.

6. Connect the power supply + post (red) to the CH 1 (X) input jack on the scope. using a BNC connector and a conductor.

a. What happened to the trace?

____

b. How far did it move?

____

c. What is the value of the DC voltage as indicated by the scope?

____

7. Have the instructor set up a different value of DC voltge.

8. Adjust the VOLTS/CM switch as required.

9. What is the DC voltage value? ________

CONFIRM YOUR ANSWERS

____

CONSULT YOUR INSTRUCTOR FOR THE PROGRESS CHECK.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

QUESTIONS:

1. Match each control with its function.

_____ a. VARIABLE VOLTS/CM (Red)
_____ b. TIME/CM
_____ c. CHOP-ALT
_____ d. CH1 ↕
_____ e. ←→
_____ f. VOLTS/CM
_____ g. VARIABLE TIME/CM (Red)
_____ h. CH1 AC-GND-DC
_____ i. FOCUS
_____ j. CAL 1V

1. Selects desired attenuation of the input signal.

2. Provides intermediate adjustment of attenuation between settings of the VOLTS/CM SWITCH.

3. Provides intermediate adjustment of sweep rate between settings of the TIME/CM switch.

4. Selects desired sweep speed.

5. Controls the location of the trace with respect to the X axis.

6. Selects the desired calibrated square wave.

7. Adjusts vertical position of CH1 display. Switches CH1 off on OFF detent.

8. Selects capacitive or direct coupling of the input signal or grounds out the input to establish a reference.

9. Adjusts for a clear, sharply defined trace.

10. Selects CHOPPED, or ALTERNATE for dual trace vertical deflection.

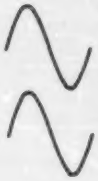
2. VARIABLE TIME/CM (Red) is set to CAL and the TIME/CM control is set to 5 mS. An AC signal is displayed on the scope and the length of one alternation is 2 cm. What is the frequency?

____ a. 50 Hz ____ b. 10 Hz

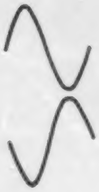
____ c. 150 Hz ____ d. 200 Hz

3. Which of the following scope presentations display a 90° phase difference?

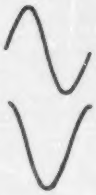
____ a.



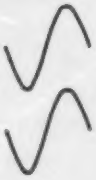
____ b.



____ c.



____ d.

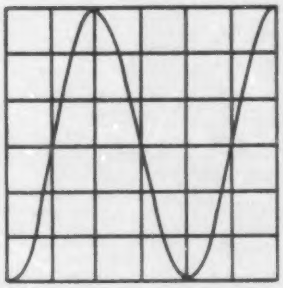


REP4-1112

4. The VARIABLE VOLTS/CM (Red) is set to CALIBRATE and the VOLTS/CM control is set on 5. An AC signal is displayed as indicated. What is the effective voltage?

____ a. 7.07 volts ____ b. 10.6 volts

____ c. 15.2 volts ____ d. 30 volts

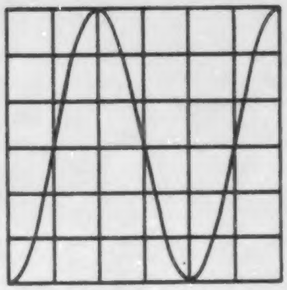


REP4-1114

5. VARIABLE TIME/CM (Red) is set to CALIBRATE and the TIME/CM control is set to 20 uS. An AC signal is displayed as indicated. What is the frequency?

____ a. 8.33 kHz ____ b. 12.5 kHz

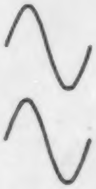
____ c. 25 kHz ____ d. 50 kHz



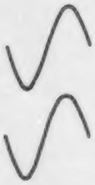
REP4-1115

6. Which of the following scope presentations display a 180° phase difference?

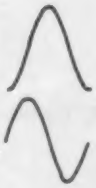
____ a.



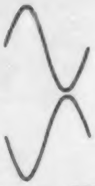
____ b.



____ c.



____ d.



REP4-1113

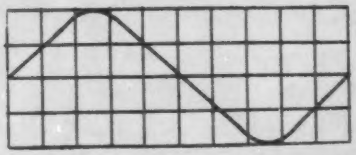
7. The VARIABLE VOLTS/DIV (Red) is set to CALIBRATE and the VOLTS/DIV control is set on 3. An AC signal is displayed as indicated. What are the effective and peak voltages?

______ a. 1.4 volt effective, 2 volts peak

______ b. 2.8 volts effective, 4 volts peak

______ c. 4.2 volts effective, 6 volts peak

______ d. 8.4 volts effective, 12 volts peak



CONFIRM YOUR ANSWERS

ANSWERS TO A - ADJUNCT GUIDE

1. b
2. b
3. a

If you missed ANY questions, review the reference material before you continue.

ANSWERS TO C - ADJUNCT GUIDE

1. 200 Hz
2a. 10 cm
2b. 5cm
2c. 2cm
3. 22.5

If you missed ANY questions, review the reference material before you continue.

ANSWERS TO E - ADJUNCT GUIDE

1. 7V peak-to-peak
2. 7.07 V
3. 2.828 cm

If you missed ANY questions, review the reference material before you continue.

ANSWERS TO LAB EXERCISE 20-1

2a. 5 b. 10 c. 9 d. 4 e. 8
f. 3 g. 7 h. 2 i. 6 j. 1
3. A-21 B-22 C-11 D-20 E-12
F-19 G-15 H-16 I-17 J-13
K-18 L-14 M-1 N-2 O-4
P-3 Q-6 R-5 S-7 T-8
U-9 V-10

If you missed any items, review the reference material before you continue.

ANSWERS TO B (20-1)

7. a
9. a

If you missed ANY questions, ask your instructor for assistance.

ANSWERS TO LAB EXERCISE 20-2

Have your instructor check your answers for questions 6, 9, 10, and 11.

For more practice on this part of the exercise, repeat steps 5 through 11.

If you missed ANY questions, ask your instructor for assistance.

ANSWERS TO LAB EXERCISE 20-3

6. CH2 VOLTS/CM and VARIABLE
7. TIME/CM and VARIABLE
9. The two signals are in phase.
11. Lead
14. Have your instructor check your answer.
16. Have your instructor check your answer.

NOTE: For more practice on measuring the phase angle between two signals, have you instructor give you different capacitor and/or resistor, and/or applied frequency values.

If you missed ANY questions, ask your instructor for assistance.

ANSWERS TO A - LAB EXERCISE 20-4

2c. 1 volt/cm
2d(1) 2 cm (2) .5 volts/cm (3) 1 volt
2e(1) .5 cm (2) 2 volts/cm (3) 1 volt
6. Have instructor verify.
8. Have instructor verify.

If you missed ANY questions, ask your instructor for assistance.

ANSWERS TO B LAB EXERCISE 20-4

6a. The trace is displaced upward.
6b. 5 cm (approximately)
6c. 10V (approximately)
9. Have instructor verify.

If you missed ANY questions, ask your instructor for assistance.

ANSWERS TO MODULE SELF-CHECK

1a. 2
b. 4
c. 10
d. 7
e. 5
f. 1
g. 3
h. 8
i. 9
j. 6
2. a
3. c
4. b
5. b
6. d
7. c

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

ATC GP 3AQR3X020-X
KEP GP-21

Technical Training

ELECTRONIC PRINCIPLES

MODULE 21

December 1975

AIR TRAINING COMMAND

7- 7

Designed For ATC Course Use

ATC Keesler 6-2556

DO NOT USE ON THE JOB

Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-21
December 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 21

SERIES RCL CIRCUITS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

Title	Page
Overview	i
List of Resources	i
Adjunct Guide	1
Laboratory Exercise 21-1	8
Module Self-Check	11
Answers	14

OVERVIEW

1. SCOPE: This module expands on your knowledge of capacitors, coils, and resistors as they apply to RCL circuits. You will compute the voltage drop, current, phase angle, impedance, and power factor for RCL circuits. Practical training is provided for examining the relationships that exist between the circuit parameters.

2. OBJECTIVES: Upon completion of this module, you should be able to satisfy the following objectives.

a. Given a series RCL circuit with applied voltage, total current, resistance values, and formulas, solve for true power and apparent power.

b. Given a series RCL circuit with component values, applied voltages, and frequency indicated, calculate the values of and plot the vectors for:

(1) Total impedance.

(2) Total current.

(3) All voltages.

(4) Approximate phase angle.

c. Using an oscilloscope and trainer, determine relative amplitude and phase relationship of E_a, E_R, E_L, and E_C in a series RCL circuit.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest

Adjunct Guide with Student Text III

Supersedes KEP-GP-21, 1 July 1975. Existing stock may be used.

AUDIOVISUALS:

TVK30-257, Series RC Circuits

TVK30-258, Series RL Circuits

LABORATORY EXERCISE:

21-1, Series RCL Circuits

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers in the back of this Guidance Package.

If you experience any difficulty, contact your instructor.

Begin the program.

A. Turn to Student Text, Volume III, and read paragraphs 1-1 through 1-6. Return to this page and answer the following questions.

1. Define impedance. ________

____

____

____

____

____

____

2. What is the phase relationship between current and applied voltage in:

a. A purely resistive circuit. ________

____

____

____

b. A purely capacitive circuit. ________

____

____

____

c. An RC circuit. ________

____

____

____

CONFIRM YOUR ANSWERS.

B. Turn to Student Text, Volume III, and read paragraphs 1-7 through 1-11. Return to this page and answer the following questions.

1. Define vector. ________

____

____

____

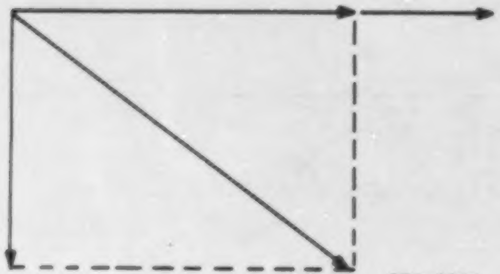
2. What is the difference between a positive and a negative angle? ________

____

____

____

3. Label the vectors in this diagram for an RC circuit.



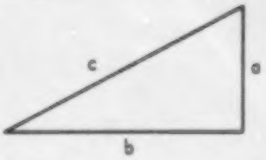
REP-1030

CONFIRM YOUR ANSWERS.

____

C. Turn to Student Text, Volume III, and read paragraphs 1-12 through 1-18. Return to this page and answer the following questions.

1. Write the Pythagorean Theorem formulas for finding each side of the right triangle shown.



REP4-1032

____

____

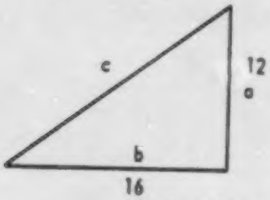
____

____

____

____

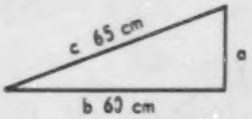
2. Solve for c in this triangle.



REP4-1033

c = ______________________________

3. Solve for a in this triangle.



REP4-1034

a = ______________________________

CONFIRM YOUR ANSWERS.

____

D. Turn to Student Text, Volume III, and read paragraphs 1-19 through 1-27. Return to this page and answer the following questions.

1. Using the table in KEP-110, find:

a. The sine of:

(1) 30°. ______________________________

(2) 45°. ______________________________

(3) 60°. ______________________________

b. The cosine of:

(1) 75°. ______________________________

(2) 45°. ______________________________

(3) 60°. ______________________________

c. The tangent of:

(1) 20°.

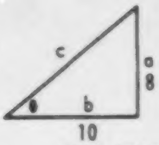
(2) 40°.

(3) 60°.

CONFIRM YOUR ANSWERS.

E. Turn to Student Text, Volume III, and read paragraphs 1-28 through 1-31. Return to this page and answer the following questions.

1. Solve for side c and angle θ for this right triangle.

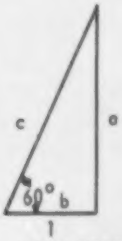


REP4-1035

c =

θ =

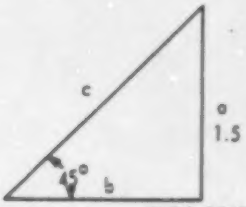
2. Solve for side a for this right triangle.



REP4-1036

a =

3. Solve for side b for this right triangle.



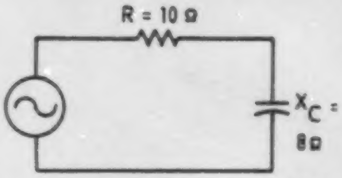
REP4-1037

b =

CONFIRM YOUR ANSWERS.

F. Turn to Student Text, Volume III, and read paragraphs 1-32 through 1-41. Return to this page and answer the following questions.

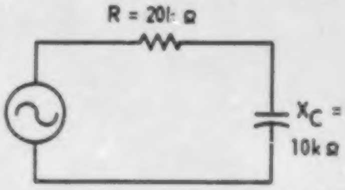
1. Solve for impedance in this RC circuit.



REP4-1038

Z =

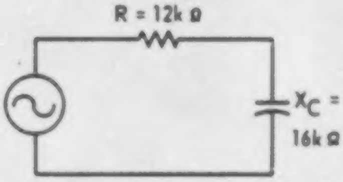
2. Solve for impedance in this circuit.



REP4-1039

Z =

3. Solve for Z in this circuit.



REP4-1040

Z =

CONFIRM YOUR ANSWERS.

G. Turn to Student Text, Volume III, and read paragraphs 1-42 through 1-52. Return to this page and answer the following questions.

1. Using the values given in the circuit diagram, solve for the listed values. Plot the impedance and voltage vectors.

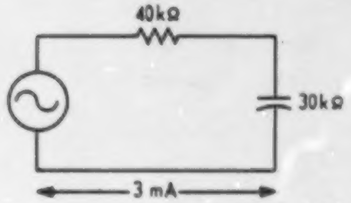
Z = ______

E_a = ______

E_R = ______

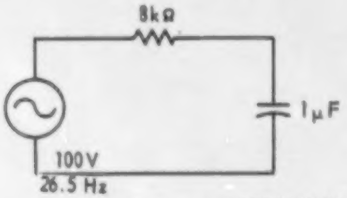
E_C = ______

θ = ______



REP4-1041

2. Solve for the indicated values. Draw the voltage and impedance vectors.



REP4-1042

Z = ______

X_C = ______

I = ______

E_R = ______

E_C = ______

θ = ______

CONFIRM YOUR ANSWERS.

H. Turn to Student Text, Volume III, and read paragraphs 2-1 through 2-6. Return to this page and answer the following questions.

1. In a purely inductive circuit, what is the phase relationship between the circuit current and applied voltage? ______

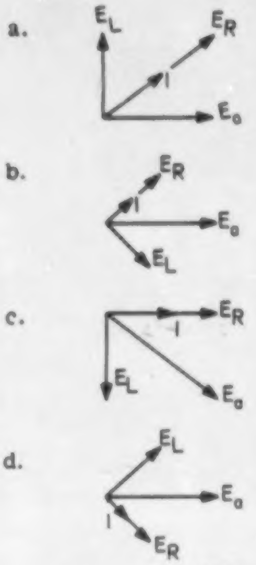
2. In a resistance inductance circuit, what is the phase relationship between current and the:

a. Applied voltage? ______

b. Inductor voltage? ______

c. Resistor voltage? ______

3. Choose the vector diagram which represents the phase relationships in an RL circuit.



REP4-1044

4. Plot the impedance vector diagram for an RL circuit in which $X_L = R$.

CONFIRM YOUR ANSWERS.

I. Turn to Student Text, Volume III, and read paragraphs 2-7 through 2-10. Return to this page and answer the following questions.

1. Use the values given to solve for the listed items. Draw the impedance and voltage vector diagrams.

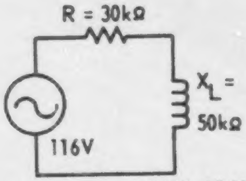
Z = ________

I = ________

E_R = ________

E_L = ________

θ = ________



REP4-1046

2. Solve for indicated values. Draw impedance and voltage vectors

X_L = ________

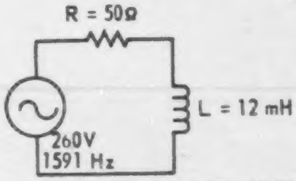
Z = ________

I = ________

E_R = ________

E_L = ________

θ = ________



REP4-1047

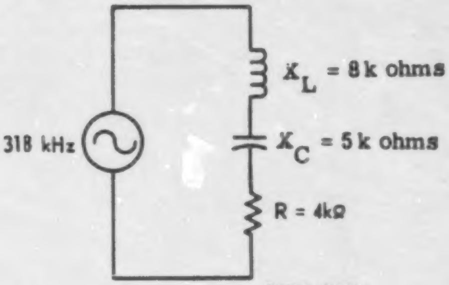
CONFIRM YOUR ANSWERS.

J. Turn to Student Text, Volume III, and read paragraphs 2-11 through 2-16. Return to this page and answer the following questions.

1. What is the phase relationship between X_L and X_C?

---

2. Draw the impedance vector diagram for this circuit.



REP4-1051

CONFIRM YOUR ANSWERS.

K. Turn to Student Text, Volume III, and read paragraphs 2-17 through 2-28. Return to this page and answer the following questions.

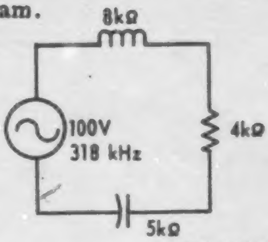
1. Solve for each of the listed items. Draw the voltage vector diagram.

I = ________

E_R = ________

E_L = ________

E_C = ________



REP4-1049

ATC Keesler 8-3284

2. Solve for the unknown values. Draw the impedance and voltage vector diagrams.

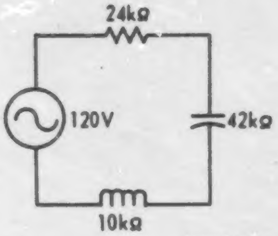
Z = ____

I = ____

E_C = ____

E_L = ____

E_R = ____



REP4-1050

CONFIRM YOUR ANSWERS.

L. Turn to Student Text, Volume III, and read paragraphs 3-1 through 3-16. Return to this page and answer the following questions.

1. Define power. ____

2. What is power in terms of current and voltage? ____

3. What is the average power in a purely capacitive circuit? ____

4. What is the average power of a purely inductive circuit? ____

5. What is the term used to describe power in a purely capacitive or a purely inductive circuit? ____

CONFIRM YOUR ANSWERS.

M. Turn to Student Text, Volume III, and read paragraphs 3-17 through 3-23. return to this page and answer the following questions.

1. Define true power ____

4. Plot the impedance vector diagram for an RL circuit in which $X_L = R$.

CONFIRM YOUR ANSWERS.

I. Turn to Student Text, Volume III, and read paragraphs 2-7 through 2-10. Return to this page and answer the following questions.

1. Use the values given to solve for the listed items. Draw the impedance and voltage vector diagrams.

Z = ______________________

I = ______________________

E_R = ______________________

E_L = ______________________

θ = ______________________

CONFIRM YOUR ANSWERS.

J. Turn to Student Text, Volume III, and read paragraphs 2-11 through 2-16. Return to this page and answer the following questions.

1. What is the phase relationship between

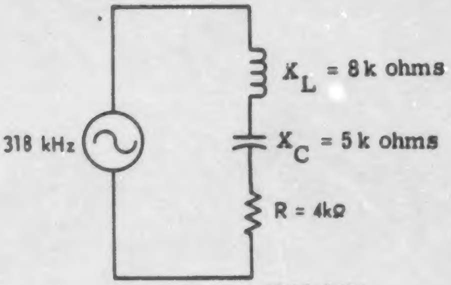
X_L and X_C? ______________________

____

____

____

2. Draw the impedance vector diagram for this circuit.



REP4-1051

CONFIRM YOUR ANSWERS.

K. Turn to Student Text, Volume III, and read paragraphs 2-17 through 2-28. Return to this page and answer the following questions.

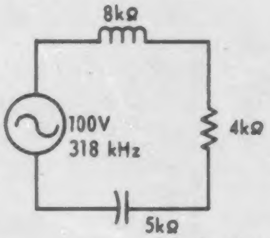
1. Solve for each of the listed items. Draw the voltage vector diagram.

I = ______________________

E_R = ______________________

E_L = ______________________

E_C = ______________________



REP4-1049

2. Solve for the unknown values. Draw the impedance and voltage vector diagrams.

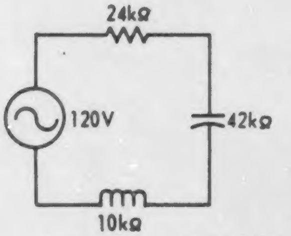
Z = ____________

I = ____________

E_C = ____________

E_L = ____________

E_R = ____________



REP4-1050

CONFIRM YOUR ANSWERS.

L. Turn to Student Text, Volume III, and read paragraphs 3-1 through 3-16. Return to this page and answer the following questions.

1. Define power. ____________

2. What is power in terms of current and voltage? ____________

3. What is the average power in a purely capacitive circuit? ____________

4. What is the average power of a purely inductive circuit? ____________

5. What is the term used to describe power in a purely capacitive or a purely inductive circuit? ____________

CONFIRM YOUR ANSWERS.

M. Turn to Student Text, Volume III, and read paragraphs 3-17 through 3-23. Return to this page and answer the following questions.

1. Define true power. ____________

2. Define apparent power and give the unit in which it is expressed. ________

____

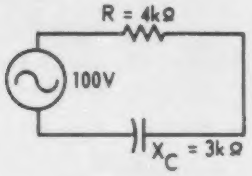
____

____

3. Determine P_t and P_a for these circuits.

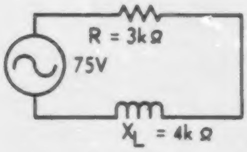
a. P_t = ________

P_a = ________


R = 4kΩ
100V
X_C = 3kΩ

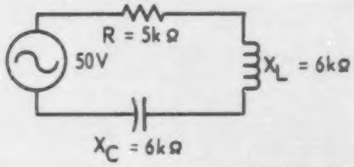
b. P_t = ________

P_a = ________


R = 3kΩ
75V
X_L = 4kΩ

c. P_t = ________

P_a = ________

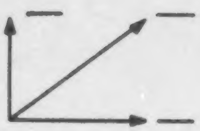

R = 5kΩ
50V
X_L = 6kΩ
X_C = 6kΩ

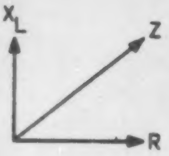
REP4-1054

CONFIRM YOUR ANSWERS.

N. Turn to Student Text, Volume III, and read paragraphs 3-24 through 3-32. Return to this page and answer the following questions.

1. Label the $P_{REACTIVE}$, P_t, and P_a vectors in the power vector diagram. The impedance vectors are given as a reference.





2. Solve for the indicated values in this problem.

Z = ________

I = ________

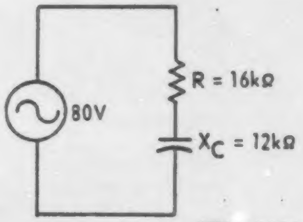
E_R = ________

E_C = ________

θ = ________

P_t = ________

P_a = ________


80V
R = 16kΩ
X_C = 12kΩ

REP4-1056

3. Solve for the indicated values.

Z = ________

I = ________

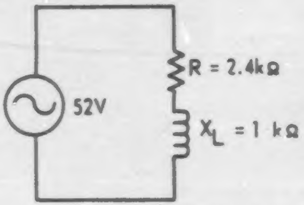
E_R = ________

E_L = ________

θ = ________

P_t = ________

P_a = ________


52V
R = 2.4kΩ
X_L = 1 kΩ

REP4-1057

4. Solve for the indicated values.

Z = ______________________

E_R = ______________________

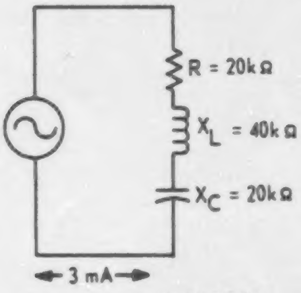
E_L = ______________________

E_C = ______________________

θ = ______________________

P_t = ______________________

P_a = ______________________



REP4-1058

CONFIRM YOUR ANSWERS.

O. Turn to Laboratory Exercise 21-1. In this exercise you will be working with a series RCL circuit, measuring component voltages and determining phase relationships.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

LABORATORY EXERCISE 21-1

OBJECTIVE: Using an oscilloscope and trainer, determine the amplitude of E_a, E_R, E_L, and E_C, and determine the phase relationship of each of the voltages in a series RCL circuit.

EQUIPMENT:

Oscilloscope, Ballantine, AN/USM-398
AC Inductor and Capacitor Trainer, 5967
Isolation Transformer, 5124
Sine Square Wave Generator, 4864

REFERENCE:

Student Text, Volume III, paragraphs 3-1 through 3-32

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

A. Measure circuit voltages.

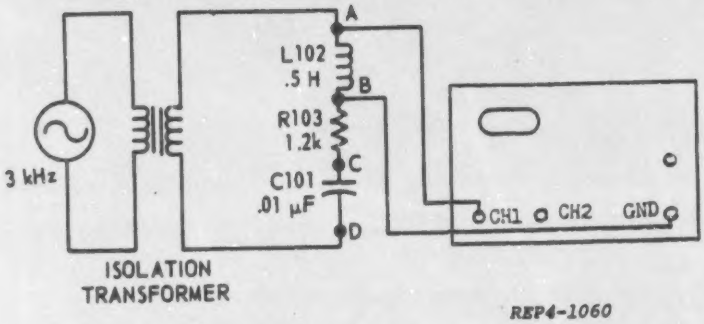
1. Set the following scope controls:

CONTROL	SETTING
POWER	ON
VOLTS/CM	0.5, CAL
CH1 AC-GND-DC	AC
CH1 Vert. Pos.	Midposition
CHOP-ALT	ALT
AC ACF-DC	AC
LEVEL	AUTO
TRIG SELECT	CH1 +
TIME/CM	0.2 mS, CAL

2. Connect the CH1 input to the output of the isolation transformer and the scope ground to the other output terminal of the isolation transformer.

3. Connect the input of the isolation transformer to the sine wave output of the generator.

4. Set the generator for a 3 kHz output that is 4 cm high on the scope.


A
L102
.5 H
B
R103
1.2k
C
C101
.01 µF
D
3 kHz
ISOLATION
TRANSFORMER
CH1
CH2
GND

REP4-1060

5. What is the peak to peak amplitude of the signal? ____________________ volts. NOTE: This will be the E_a to the RCL circuit.

6. Connect the circuit as shown in the diagram at the top of this page.

7. Which component voltage is being viewed on the scope? ____________________

8. What is the peak to peak value? ________

____

9. Move the scope ground lead to point D and the CH1 input to point C.

10. What is the peak to peak value of E_C? ____________________ volts.

11. Move the scope ground lead to point C and the CH1 input to point B.

12. What is the peak to peak value of E_R? It may be necessary to change the VOLTS/CM setting to get a clear reading. _____ volts.

CONFIRM YOUR ANSWERS.

B. Phase relationships.

1. Connect the scope as shown in the figure at the bottom of this page.

2. Make these scope adjustments:

CONTROL	SETTING
TRIG SELECT	EXT +
CH2 AC-GND-DC	AC
CH2 Vert. Pos.	Midposition

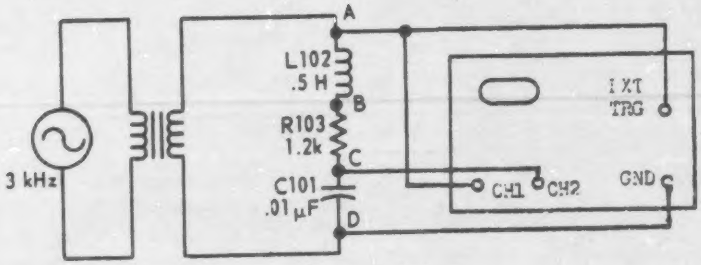
3. Connect EXT TRIG to point A in the circuit.

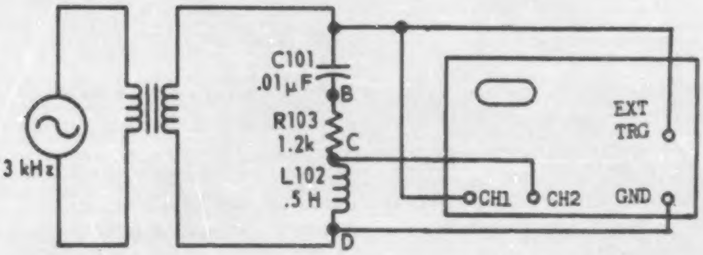
4. Connect CH1 input to point A in the circuit.

5. Connect scope ground to point D in the circuit.

6. Connect the CH2 input to point C.

7. Turn CH2 until a second signal is viewed on the screen.


A
L102
.5 H
B
R103
1.2k
C
C101
.01 µF
D
3 kHz
EXT
TRG
CH1
CH2
GND


C101
.01 μF
B
R103
1.2k
C
L102
.5 H
D
3 kHz
EXT
TRG
CH1
CH2
GND

8. Adjust the TIME/CM switch and the VARIABLE control so one sine wave is exactly 8 cm long.

9. Adjust the scope controls so that the two signals are equal in amplitude.

10. What voltage is displayed on CH1?

____

11. What voltage is displayed on CH2?

____

12. Is E_C in phase with E_a? Channel 1 is displaying E_a. ____________________

13. How many centimeters separate the two signals? ____________________

14. What is the phase difference between the two signals? ______________ degrees.

CONFIRM YOUR ANSWERS.

15. To compare E_a and E_L, reconnect the circuit as shown in the above illustration.

16. Adjust the scope so E_L and E_a have the same amplitude and one sine wave is 8 cm long.

17. The phase difference between the two signals is __________________ cm or ________________ degrees.

CONFIRM YOUR ANSWERS.

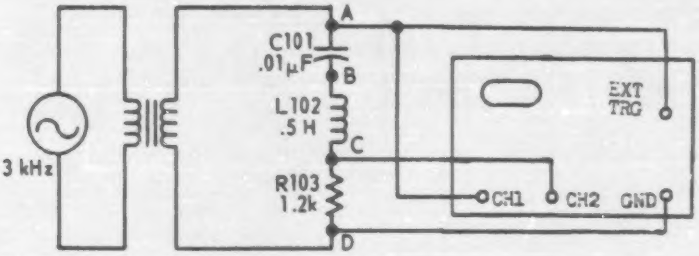
18. Set up the circuit shown at the bottom of this page to compare E_R with E_a.

19. Adjust the scope so E_R and E_a have the same amplitude and one cycle is 8 cm long.

20. The phase difference between the two signals is __________________ cm or ________________ degrees.

21. Disconnect the equipment.

CONFIRM YOUR ANSWERS.


A
C101
.01 μF
B
L102
.5 H
C
R103
1.2k
D
3 kHz
EXT
TRG
CH1
CH2
GND

CONSULT YOUR INSTRUCTOR FOR THE PROGRESS CHECK.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

1. Solve for:

Z =

I =

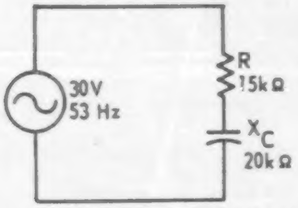
E_R =

E_C =

P_t =

P_a =

θ =


30V
53 Hz
R
15kΩ
X_C
20kΩ

REP4-1064

Draw the impedance vectors.

2. Solve for:

Z =

I =

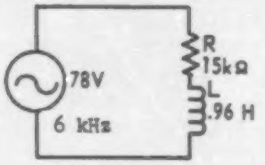
E_R =

E_L =

P_t =

P_a =

θ =


78V
6 kHz
R
15kΩ
L
.96 H

REP4-1065

Draw the voltage vectors using E_a as the reference.

3. Solve for:

X_C =

Z =

I =

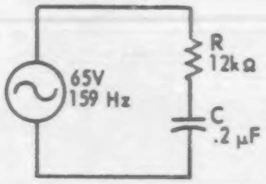
E_R =

E_C =

P_t =

P_a =

θ =


65V
159 Hz
R
12kΩ
C
.2 μF

REP4-1066

Draw the voltage vectors using E_a as the reference.

4. Solve for:

Z = ______

I = ______

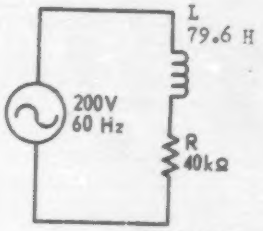
E_R = ______

E_L = ______

θ = ______

P_t = ______

P_a = ______


L
79.6 H
200V
60 Hz
R
40kΩ

REP4-1067

Draw the impedance vectors.

5. Solve for:

X_L = ______

X_C = ______

Z = ______

I = ______

E_L = ______

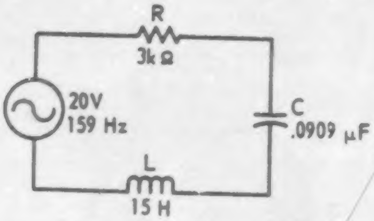
E_C = ______

E_R = ______

θ = ______

P_t = ______

P_a = ______


R
3kΩ
20V
159 Hz
C
.0909 μF
L
15 H

REP4-1068

Draw the impedance vectors.

6. **Solve for:**

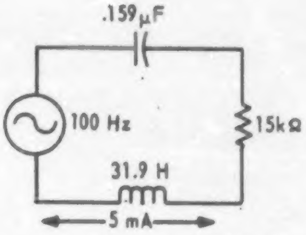
E_C = ____________________

E_L = ____________________

E_R = ____________________

P_t = ____________________

P_a = ____________________


.159μF
100 Hz
15kΩ
31.9 H
5 mA

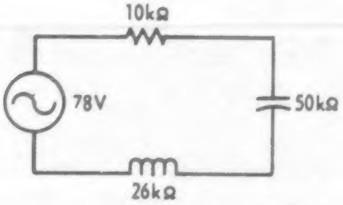
REP4-1069

Draw the voltage vectors using E_a as the reference.

7. Solve for:

P_t = ____________________

P_a = ____________________


10kΩ
78V
50kΩ
26kΩ

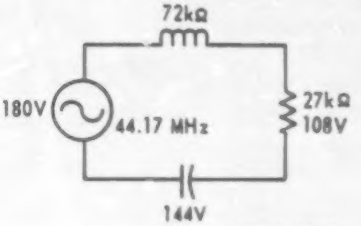
REP4-1070

Draw the impedance vectors.

8. **Solve for:**

P_t = ____________________

P_a = ____________________


72kΩ
180V
44.17 MHz
27kΩ
108V
144V

REP4-1071

Draw the impedance vectors.

CONFIRM YOUR ANSWERS.

ANSWERS TO A - ADJUNCT GUIDE:

1. Impedance is the total opposition offered to the flow of alternating current.

2. a. Current and voltage are in phase.

   b. Current leads the voltage by 90°.

   c. Current leads the voltage by less than 90°.

If you missed ANY questions, review the material before you continue.

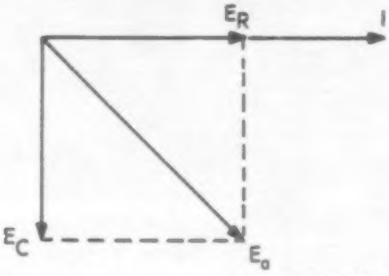
ANSWERS TO B - ADJUNCT GUIDE:

1. A vector is a line used to represent magnitude and direction.

2. A positive angle is generated when a vector is rotated CCW.

A negative angle is generated when a vector is rotated CW.

3.



REP4-1031

If you missed ANY questions, review the material before you continue.

ANSWERS TO C - ADJUNCT GUIDE:

1.

$$c = \sqrt{a^2 + b^2}$$
$$a = \sqrt{c^2 - b^2}$$
$$b = \sqrt{c^2 - a^2}$$

2. 20

3. 25 cm

If you missed ANY questions, review the material before you continue.

ANSWERS TO D - ADJUNCT GUIDE:

1. a. (1) .5000 (2) .7071 (3) .8660

   b. (1) .2588 (2) .7071 (3) .5000

   c. (1) .3640 (2) .8391 (3) 1.7321

If you missed ANY questions, review the material before you continue.

ANSWERS TO E - ADJUNCT GUIDE:

1. $c = 12.8$ $\theta = 38.7°$

2. $a = 1.7321$

3. $b = 1.5$

If you missed ANY questions, review the material before you continue.

ANSWERS TO F - ADJUNCT GUIDE:

1. Z = 12.81 ohms

2. Z = 22.4 k ohms

3. Z = 20 k ohms

If you missed ANY questions, review the material before you continue.

ANSWERS TO G - ADJUNCT GUIDE:

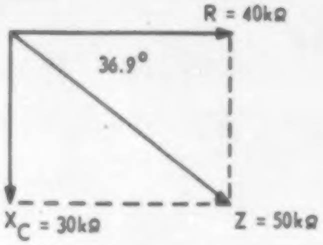
1. Z = 50 k ohms

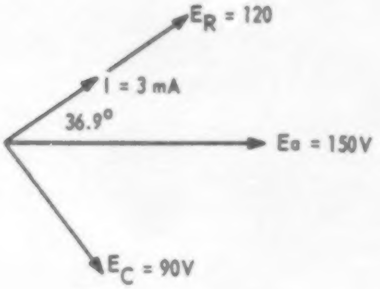
   E_a = 150V

   E_R = 120V

$E_C = 90V$

$\theta = 36.9°$


R = 40kΩ
36.9°
X_C = 30kΩ
Z = 50kΩ


E_R = 120
I = 3 mA
36.9°
Ea = 150V
E_C = 90V

2. $Z = 10$ k ohms

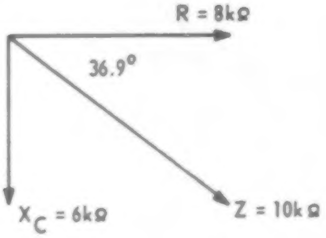
$X_C = 6$ k ohms

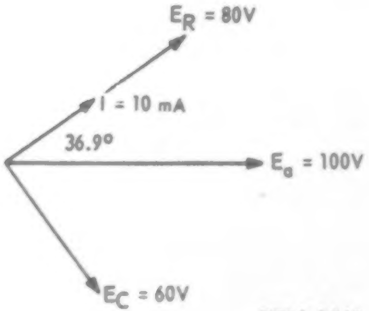
$I = 10$ mA

$E_R = 80V$

$E_C = 60V$

$\theta = 36.9°$


R = 8kΩ
36.9°
X_C = 6kΩ
Z = 10kΩ


E_R = 80V
I = 10 mA
36.9°
E_a = 100V
E_C = 60V

REP4-1043

If you missed ANY questions, review the material before you continue.

ANSWERS TO H - ADJUNCT GUIDE:

1. Current lags the applied voltage by 90°.

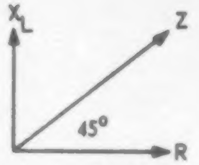
2. Current lags the applied voltage by less than 90°.

   Current lags E_L by 90°.

   Current and E_R are in phase.

3. d

4.



REP4-1045

If you missed ANY questions, review the material before you continue.

ANSWERS TO I - ADJUNCT GUIDE:

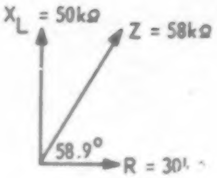
1. $Z = 58$ k ohms

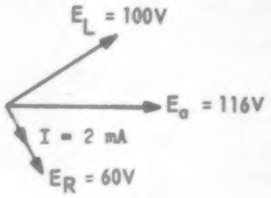
   $I = 2$ mA

   $E_R = 60V$

   $E_L = 100V$

   θ - 58.9°


X_L = 50kΩ
Z = 58kΩ
58.9°
R = 30k


E_L = 100V
E_a = 116V
I = 2 mA
E_R = 60V

2. X_L = 120 ohms

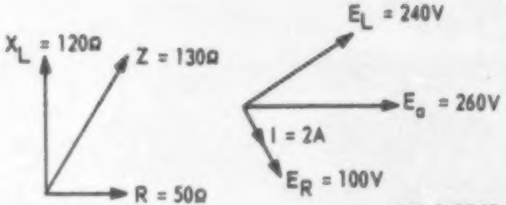
Z = 130 ohms

I = 2 A

E_R = 100V

E_L = 240V

θ = 67.4°


X_L = 120Ω
Z = 130Ω
R = 50Ω
E_L = 240V
E_a = 260V
I = 2A
E_R = 100V

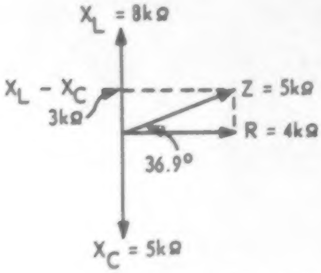
REP4-1048

If you missed ANY questions, review the material before you continue.

ANSWERS TO J - ADJUNCT GUIDE:

1. X_L and X_C are 180° out of phase.

2.


X_L = 8kΩ
X_L − X_C
3kΩ
Z = 5kΩ
R = 4kΩ
36.9°
X_C = 5kΩ

REP4-1052

If you missed ANY questions, review the material before you continue.

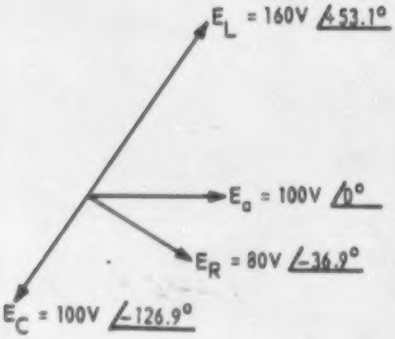
ANSWERS TO K - ADJUNCT GUIDE:

1. I = 20 ma $\angle\underline{-36.9°}$

E_R = 80V $\angle\underline{-36.9°}$

E_L = 160V $\angle\underline{+53.1°}$

E_C = 100V $\angle\underline{-126.9°}$


E_L = 160V ∠53.1°
E_a = 100V ∠0°
E_R = 80V ∠-36.9°
E_C = 100V ∠-126.9°

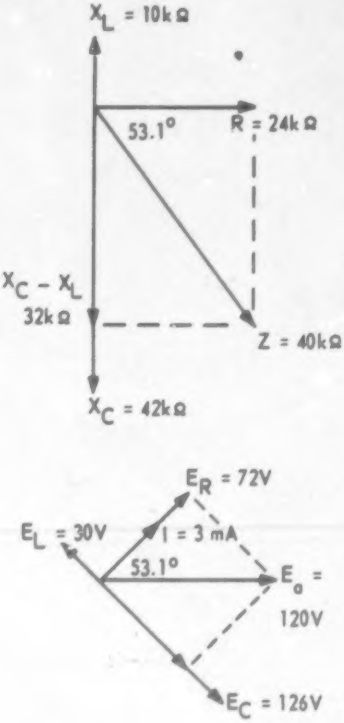
2. Z = 40 k ohms

I = 3 mA

E_C = 126V

E_L = 30V

E_R = 72V


X_L = 10kΩ
53.1°
R = 24kΩ
X_C − X_L
32kΩ
Z = 40kΩ
X_C = 42kΩ
E_R = 72V
E_L = 30V
I = 3 mA
53.1°
E_a = 120V
E_C = 126V

REP4-1053

If you missed ANY questions, review the material before you continue.

ANSWERS TO L - ADJUNCT GUIDE:

1. Power is rate of doing work.

2. $P = I \times E$

3. The average power in a purely capacitive circuit is zero.

4. Zero

5. Apparent power

If you missed ANY questions, review the material before you continue.

ANSWERS TO M - ADJUNCT GUIDE:

1. True power is the actual power dissipated by the circuit resistance.

2. Apparent power is the product of current times voltage, and is expressed in volt-amperes.

3. a. $P_t = 1.6W$

   $P_a = 2$ VA

   b. $P_t = 675$ mW

   $P_a = 1.125$ mVA

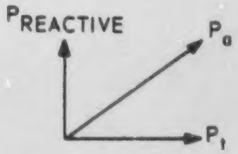
   c. $P_t = 500$ mW

   $P_a = 500$ mVA

If you missed ANY questions, review the material before you continue.

ANSWERS TO N - ADJUNCT GUIDE:

1.



REP4-1059

2. $Z = 20$ k ohms

   $I = 4$ mA

   $E_R = 64V$

   $E_C = 48V$

   $\theta = 36.9^\circ$

   $P_t = 256$ mW

   $P_a = 320$ mVA

3. $Z = 2.6$ k ohms

   $I = 20$ mA

   $E_R = 48V$

   $E_L = 20V$

   $\theta = 22.6^\circ$

   $P_t = 960$ mW

   $P_a = 1040$ mVA

4. $Z = 28.28$ k ohms

   $E_R = 60V$

   $E_L = 120V$

   $E_C = 60V$

   $\theta = 45^\circ$

   $P_t = 180$ mW

   $P_a = 254.52$ mVA

If you missed ANY questions, review the material before you continue.

ANSWERS TO A - LAB EXERCISE:

5. 20V peak to peak

7. E_L

8. Have instructor verify.

10. Have instructor verify.

11. Have instructor verify.

If you missed ANY questions, ask your instructor for assistance.

ANSWERS TO B - LAB EXERCISE:

10. E_a

11. E_C

12. No

13. Have your instructor verify your answer.

14. Have your instructor verify your answer.

If you missed ANY questions, ask your instructor for assistance.

---

17. Have your instructor verify your answers.

If you missed any questions, ask your instructor for assistance.

---

20. Have your instructor verify your answers.

If you missed ANY questions, ask your instructor for assistance.

ANSWERS TO MODULE SELF-CHECK:

1. $Z = 25$ k ohms

$E_C = 24V$

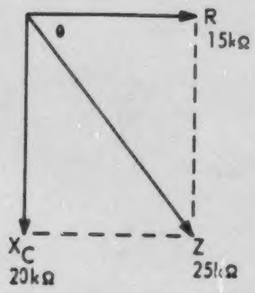
$I = 1.2$ mA

$P_t = 21.6$ mW

$\theta = 53.1°$

$E_R = 18V$

$P_a = 36$ mVA



REP4-1072

2. $Z = 39$ k ohms

$E_L = 72V$

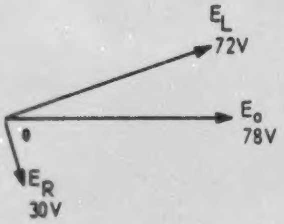
$I = 2$ mA

$P_t = 60$ mW

$\theta = 67.4°$

$E_R = 30V$

$P_a = 156$ mVA



REP4-1073

3. $X_C = 5$ k ohms

$E_R = 60V$

$P_a = 325$ mVA

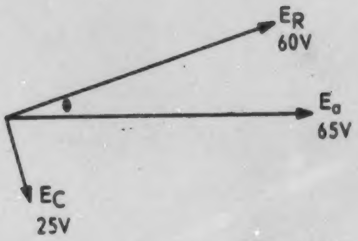
$Z = 13$ k ohms

$E_C = 25V$

$I = 5$ mA

$P_t = 300$ mW

$\theta = 22.6°$


E_R
60V
θ
E_a
65V
E_C
25V

REP4-1074

4. Z = 50 k ohms

E_L = 120V

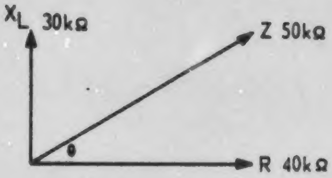
P_t = 640 mW

I = 4 mA

θ = 36.9°

P_a = 800 mVA

E_R = 160V


X_L 30kΩ
Z 50kΩ
θ
R 40kΩ

REP4-718

5. X_L = 15 k ohms

I = 4 mA

E_R = 12V

P_a = 80 mVA

X_C = 11 k ohms

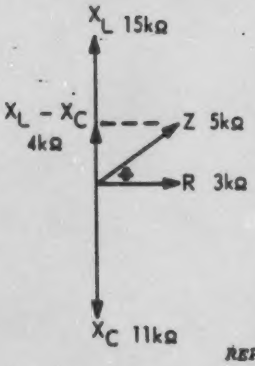
E_L = 60V

θ = 53.1°

Z = 5 k ohms

E_C = 44V

P_t = 48 mW


X_L 15kΩ
$X_L - X_C$
4kΩ
Z 5kΩ
θ
R 3kΩ
X_C 11kΩ

REP4-726

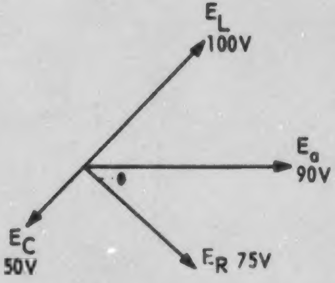
6. E_C = 50V

P_t = 375 mW

E_L = 100V

P_a = 450 mVA

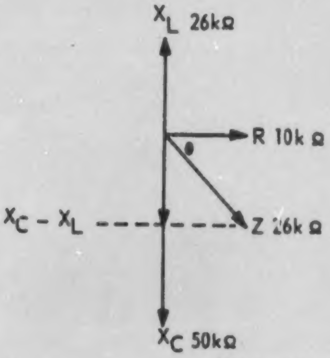
E_R = 75V


E_L
100V
E_a
90V
θ
E_C
50V
E_R 75V

REP4-1075

7. P_t = 90 mW

P_a = 234 mVA

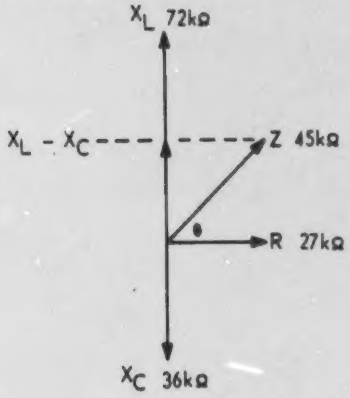

X_L 26kΩ
R 10k Ω
θ
$X_C - X_L$
Z 26k Ω
X_C 50kΩ

REP4-1076

188

8. P_t = 432 mW

P_a = 720 mVA


X_L 72kΩ
$X_L - X_C$
Z 45kΩ
θ
R 27kΩ
X_C 36kΩ

REP4-1077

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

PREPARE THE MAN

ATC PT 3AQR3X020-X

Prepared by Keesler TTC
KEP-PT-21

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 21

SERIES REACTIVE CIRCUITS (NONRESONANT)

1 January 1975

AIR TRAINING COMMAND

7-7

Designed For ATC Course Use

DO NOT USE ON THE JOB

Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

Programmed Text 3AQR3X020-X
KEP-PT-21

This illustrated Programmed Text is designed to aid in the study of Series Reactive Circuits. Each page contains an important idea or concept to be understood before proceeding to the next. An illustration for each objective is presented to clarify what is to be learned.

At the bottom of each page, there are a few questions to bring out the main points. These are indicated by.... It is hoped that these questions also aid understanding the subject a little better.

Q-1 or Q-2 etc..

The answers to these questions will be found on the top of a following page, indicated as.... Short comments may follow the answers to help understand why a question may have been missed.

A-1 or A-2 etc..

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OBJECTIVES

Upon completion of this module, you should be able to satisfy the following objectives:

a. Given an AC series RCL circuit with applied voltage, total current, resistance values, and formulas, solve for true power and apparent power.

b. Given a series RCL circuit with component values, applied voltage, and frequency indicated, calculate the values of and plot the vectors for
   (1) total impedance.
   (2) total current.
   (3) all voltages.
   (4) approximate phase angle.

c. Using an oscilloscope and trainer, determine relative amplitude and phase relationship of E_a, E_R, E_L, and E_C, in a series RCL circuit.

INTRODUCTION

Most electronic equipment is constructed of series and parallel connected "reactive" components. All audio and video circuits, operate as frequency sensitive "reactive" circuits. Resistors, capacitors, and inductors, operating together, form the "heart" of complex receivers, transmitters, control and indicating assemblies.

Transistors and tubes depend upon proper "cooperation" between resistors, capacitors, and inductors, connected to their terminals. Failure of such components to "react" properly together, will disable the entire circuit, and result in "system" troubles often difficult to locate. The service technician must therefore have a "working knowledge" of how these three components control the performance of most Electronic circuits.

The study of how these components "work together" is called Series Reactive Circuits. It is a complex and difficult subject, requiring several different approaches to understand how the three electronic parts join their operating characteristics into "one" result.

This text is divided into two such "approaches". 1. The circuits, their theory of operation, and calculations. 2. Vector diagrams, and how to use them.

The study begins with "Impedance", and what it consists of.

IMPEDANCE

The total opposition, in any alternating current circuit, is called IMPEDANCE. (Symbol Z)

Most AC circuits are made up of combinations of Resistance (R), Capacitive Reactance (X_C), and Inductive Reactance (X_L). Lumped together, these differing oppositions form a total called IMPEDANCE (Z).

As with all oppositions, IMPEDANCE is measured in OHMS Ω, kΩ, or MΩ. EXAMPLE: "The impedance of this circuit = 2kΩ".

Q-1 a. The total opposition in any alternating current circuit, is called ______________________.

b. The combination of Resistance and Reactance is called _________.

c. Impedance (Z) is the ________________ opposition of AC circuits.

d. T-F. Impedance (Z) is measured in amperes.

e. T-F. Impedance (Z) is measured in volts.

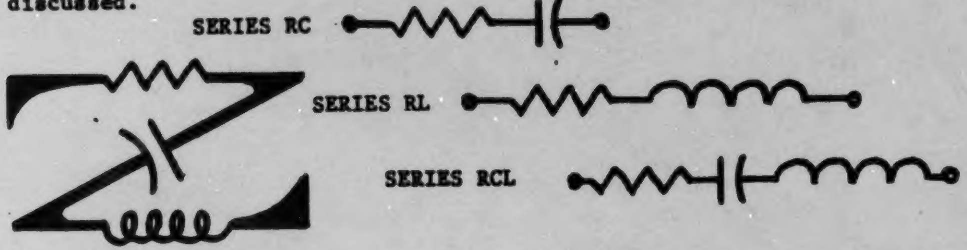
f. Impedance is measured in ________, just like other oppositions.

g. The symbol used for Impedance is ________.

h. T-F. Impedance (Z) in alternating current circuits, is similiar to Total Resistance (R_t) in Direct Current circuits.

SERIES REACTIVE CIRCUITS

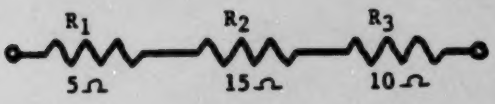
Three types of alternating current series circuits will be discussed.



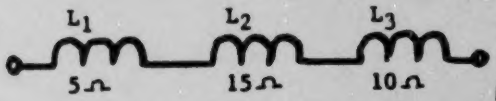
In these "reactive circuits", the total opposition or IMPEDANCE (Z) plays an important part. The total opposition limits the amount of current which is allowed to flow, and determines the rest of the circuit operating characteristics which will be discussed later.

CALCULATING TOTAL OPPOSITIONS

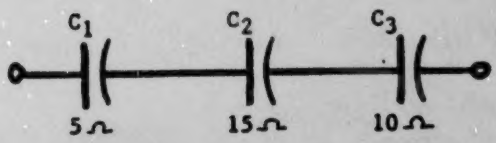
When the individual oppositions in a series circuit are all the same type, the total opposition is obtained thru simple addition.



$$\begin{aligned} R_t &= R_1 + R_2 + R_3 \\ &= 5 + 15 + 10 \\ &= 30\Omega \end{aligned}$$



$$\begin{aligned} X_{L_T} &= X_{L_1} + X_{L_2} + X_{L_3} \\ &= 5 + 15 + 10 \\ &= 30\Omega \end{aligned}$$



$$\begin{aligned} X_{C_T} &= X_{C_1} + X_{C_2} + X_{C_3} \\ &= 5 + 15 + 10 \\ &= 30\Omega \end{aligned}$$

Q-2 a. The total opposition in an alternating current circuit, is called ____________________.
b. Impedance (Z) will limit or control ____________.
c. Impedance (Z) is measured in ___________.
d. If the total opposition (Impedance) increases, the amount of current allowed to flow will ________________(inc or dec)
e. T-F When oppositions are the same type, they are added together.

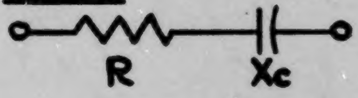
A-1
a. Impedance....symbol (Z)
b. Impedance....Reactance meaning either Inductive Reactance (X_L), or Capacitive Reactance (X_C).
c. total, overall, or complete
d. False......ohms
e. False......ohms
f. ohms
g. (Z)
h. True, Impedance will limit current.

CALCULATING IMPEDANCE

The total opposition of a "reactive circuit" is also obtained thru addition. However, because the types of opposition are different, the total opposition (Z) must be calculated in special ways.

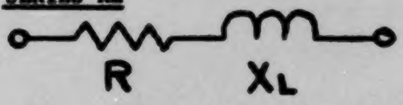
CIRCUITS	IMPEDANCE EQUATIONS

SERIES RC



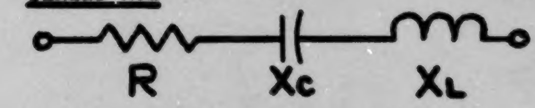
$$Z = \sqrt{R^2 + X_C^2}$$

SERIES RL



$$Z = \sqrt{R^2 + X_L^2}$$

SERIES RCL



$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

These equations may appear difficult, however they are actually quite simple when it gets down to using them. Example problems will follow, but practice using the "square root table" comes first.

Q-3 Using the Square Root Tables in KEP-110 Electronics Handbook, look up the "squares" of the following numbers:

a. 26^2 = _____ b. 85^2 = _____ c. 124^2 = _____ d. 458^2 = _______

Using the same tables, look up the "square root" of the following:

e. $\sqrt{16}$ = _____ f. $\sqrt{96}$ = _____ g. $\sqrt{145}$ = _____ h. $\sqrt{856}$ = _____

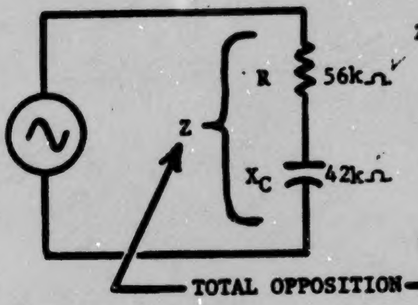
The "square root" of numbers over 1000 is determined by looking for the number in the "square" column, then sliding over into the "number" column for the answer.

i. $\sqrt{1,225}$ = _____ j. $\sqrt{6,084}$ = _____ k. $\sqrt{19,600}$ = _____

A-2
- a. Impedance....symbol (Z)
- b. current, or total current
- c. ohms, k ohms, or M ohms
- d. decrease....increasing opposition always reduces current.
- e. True....but they must be exactly the same type of oppositions.

CALCULATING IMPEDANCE (cont)

The total opposition or IMPEDANCE (Z) of a Series RC Circuit, is calculated as follows. Use the "tables" to check each step...



$Z = \sqrt{R^2 + X_C^2}$ Z equation.

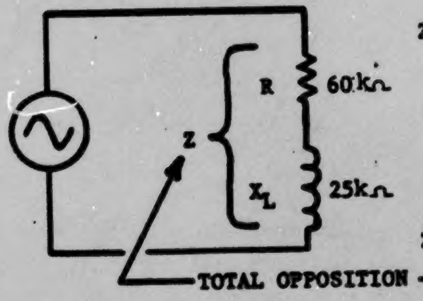
$= \sqrt{56^2 + 42^2}$ kΩ is dropped.

$= \sqrt{3{,}136 + 1{,}764}$ From the "tables".

$= \sqrt{4{,}900}$ Added together.

$Z = \boxed{70\text{ k}\Omega}$ From the "tables" with kΩ added back on.

The total opposition or IMPEDANCE (Z) of a Series RL Circuit, is calculated by the same method, using a slightly different equation.....



$Z = \sqrt{R^2 + X_L^2}$ Z equation.

$= \sqrt{60^2 + 25^2}$ kΩ is dropped.

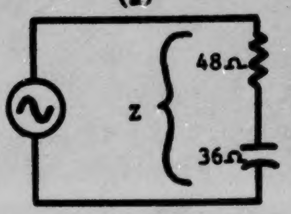
$= \sqrt{3{,}600 + 625}$ From the "tables".

$= \sqrt{4{,}225}$ Added together.

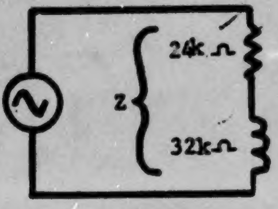
$Z = \boxed{65\text{ k}\Omega}$ From the "tables" with kΩ added back on.

Q-4 Calculate the total opposition or IMPEDANCE (Z) of these circuits.

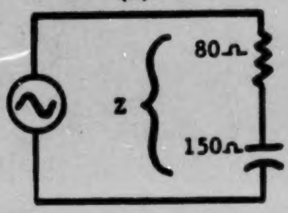
(a)



(b)



(c)



A-3

a. 676
b. 7,225
c. 15,376
d. 209.764
e. 4
f. 9.7980
g. 12.0416
h. 29.2575
i. 35
j. 78
k. 140

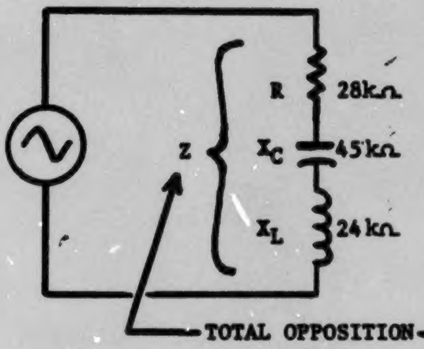
CALCULATING IMPEDANCE (cont)

The total opposition or IMPEDANCE (Z) of a Series RCL Circuit, is calculated in a similar manner.

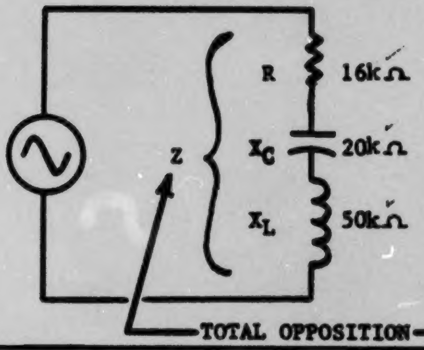
NOTE THE DIFFERENCE

$$Z = \sqrt{R^2 + (X_C - X_L)^2} \qquad Z = \sqrt{R^2 + (X_L - X_C)^2}$$

The equation used, depends upon which opposition (X_C or X_L) is the larger Use the "tables" to check each example step.....


R
28kΩ
Z
X_C
45kΩ
X_L
24kΩ
TOTAL OPPOSITION

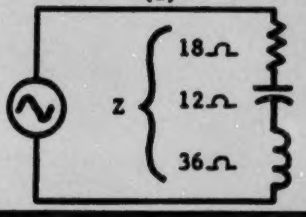
$Z = \sqrt{R^2 + (X_C - X_L)^2}$ Z equation
$= \sqrt{28^2 + (45 - 24)^2}$ k dropped
$= \sqrt{28^2 + (\ 21\ )^2}$ Subtract
$= \sqrt{784 + 441}$ From tables
$= \sqrt{1,225}$ Added
$Z = \boxed{35\ K\Omega}$ From tables


R
16kΩ
Z
X_C
20kΩ
X_L
50kΩ
TOTAL OPPOSITION

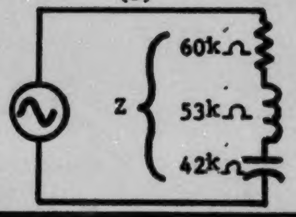
$Z = \sqrt{R^2 + (X_L - X_C)^2}$ Z equation
$= \sqrt{16^2 + (50 - 20)^2}$ k dropped
$= \sqrt{16^2 + (\ 30\ )^2}$ Subtract
$= \sqrt{256 + 900}$ From tables
$= \sqrt{1,156}$ Added
$Z = \boxed{34\ k\Omega}$ From tables

Q-5 Calculate the total opposition or IMPEDANCE (Z) of these circuits.

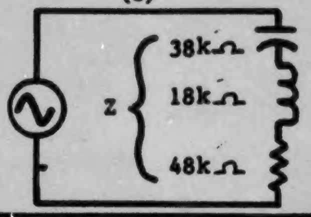
(a)


Z
18Ω
12Ω
36Ω

(b)


Z
60kΩ
53kΩ
42kΩ

(c)


Z
38kΩ
18kΩ
48kΩ

A-4 a. 60Ω b. 40kΩ c. 170Ω

CALCULATING TOTAL CURRENT

Once the IMPEDANCE (Z) of a Series Reactive Circuit has been determined, the calculation for TOTAL CURRENT (I_t) is the next step.

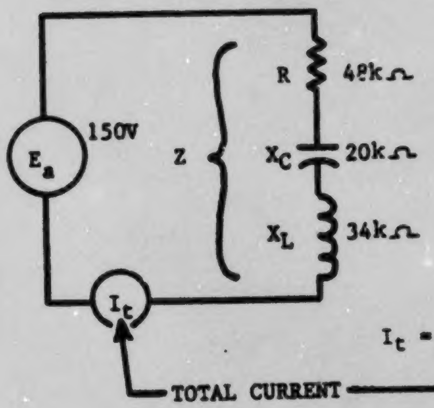
I_t = Total Current (to be calculated)

E_a = Applied Voltage (from the generator)

Z = Impedance (previously determined)

$$\boxed{I_t = \frac{E_a}{Z}}$$

EXAMPLE:



$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= \sqrt{48^2 + (34 - 20)^2}$$

$$= \sqrt{48^2 + (\ 14\ )^2}$$

$$= \sqrt{2{,}304 + 196}$$

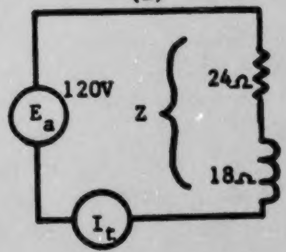
$$= \sqrt{2{,}500}$$

$$Z = \boxed{50\ k\Omega}$$

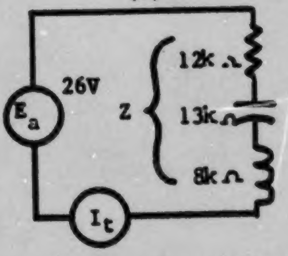
$$I_t = \frac{E_a}{Z} = \frac{150V}{50\,k\Omega} = \boxed{3\ mA}$$

Q-6 Solve for Total Current (I_t) in the following circuits.

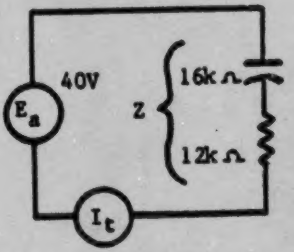
(a)



(b)



(c)



d. What would happen to the Impedance of circuit (a) if the opposition of the resistor is increased? __________(inc or dec)

e. What would happen to the impedance of (a), if the frequency from the generator decreases? ________(inc or dec)

f. What would happen to the impedance of (c), if the opposition of the resistor is increased? __________(inc or dec)

g. What would happen to the impedance of (c), if the frequency from the generator is increased? ________(inc or dec)

h. What would happen to the total current in (b) if the opposition of the resistor is increased? ___________(inc or dec)

A-5 a. 30Ω b. 61kΩ c. 52kΩ

VOLTAGE DROPS

Current flowing in a Reactive Circuit, will cause voltage drops to occur across each component.

- E_R Resistor Voltage Drop
- E_C Capacitor Voltage Drop
- E_L Inductor Voltage Drop

CALCULATING VOLTAGE DROPS

Following the calculations for Impedance (Z) and Total Current (I_t), the individual component voltage drops are determined by Ohms Law.

Ohms' Law

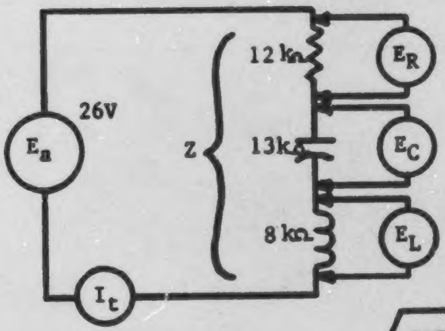
VOLTAGE = CURRENT × OPPOSITION

RESISTOR VOLTAGE $E_R = I_t \times R$

CAPACITOR VOLTAGE $E_C = I_t \times X_C$

INDUCTOR VOLTAGE $E_L = I_t \times X_L$

EXAMPLE:



$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$
$$= \sqrt{12^2 + (13 - 8)^2}$$
$$= \sqrt{12^2 + (5)^2}$$
$$= \sqrt{144 + 25}$$
$$= \sqrt{169}$$

IMPEDANCE = 13 Ω

TOTAL CURRENT $I_t = \frac{E_a}{Z} = \frac{26V}{13k} = 2mA$

Now calculate the component voltage drops....

$E_R = I_t \cdot R$
$= 2mA \cdot 12k\Omega$
$= 24V$

$E_C = I_t \cdot X_C$
$= 2mA \cdot 13k\Omega$
$= 26V$

$E_L = I_t \cdot X_L$
$= 2mA \cdot 8k\Omega$
$= 16V$

NOTE: The sum of the individual voltage drops does NOT equal the Applied Voltage. It is NOT supposed to....reasons, later.

Q-7 a. In Reactive Circuits the voltage drops are calculated using __________ Law.
b. A voltage drop will occur when __________ flows thru a resistor, a capacitor, or an inductor.

A-6

a. 4A (Z = 30Ω)

b. 2mA (Z = 13kΩ)

c. 2mA (Z = 20kΩ)

d. Increase...an increase of either opposition would increase the total opposition.

e. Decrease...if freq decreases, X_L decreases, and the total opposition would decrease.

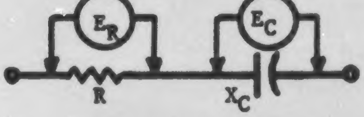
f. Increase...if either opposition increases, the total opposition would increase.

g. Decrease...if freq increases, X_C decreases, and the total opposition would decrease.

h. Decrease...if R increases, Z increases, and the increase of opposition decreases I_t.

VOLTAGE DROPS (cont)

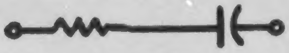
The individual oppositions (R, X_C, and X_L) were added together in a special way to obtain the total opposition (Z). Therefore, the individual voltage drops (E_R, E_C, and E_L) will have to be added together in the same special way to equal the applied voltage (E_a).

	IMPEDANCE	APPLIED VOLTAGE
	$Z = \sqrt{R^2 + X_C^2}$	$E_a = \sqrt{E_R^2 + E_C^2}$

A-7 a. Ohms Law.... VOLTAGE = CURRENT · OPPOSITION
b. current..... remembering that current does NOT flow "thru" a capacitor due to the "dielectric". What is meant, is current flowing in a circuit, containing a capacitor.

EQUATION SUMMARY

SERIES RC



$$Z = \sqrt{R^2 + X_C^2}$$

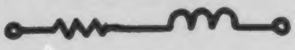
$$I_t = \frac{E_a}{Z}$$

$$E_R = I_t \cdot R$$

$$E_C = I_t \cdot X_C$$

$$E_a = \sqrt{E_R^2 + E_C^2}$$

SERIES RL



$$Z = \sqrt{R^2 + X_L^2}$$

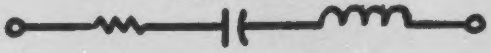
$$I_t = \frac{E_a}{Z}$$

$$E_R = I_t \cdot R$$

$$E_L = I_t \cdot X_L$$

$$E_a = \sqrt{E_R^2 + E_L^2}$$

SERIES RCL



X_C greater than X_L

$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$

$$E_a = \sqrt{E_R^2 + (E_C - E_L)^2}$$

X_L greater than X_C

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$E_a = \sqrt{E_R^2 + (E_L - E_C)^2}$$

$$I_t = \frac{E_a}{Z}$$

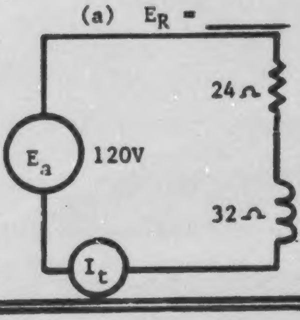
$$E_R = I_t \cdot R$$

$$E_C = I_t \cdot X_C$$

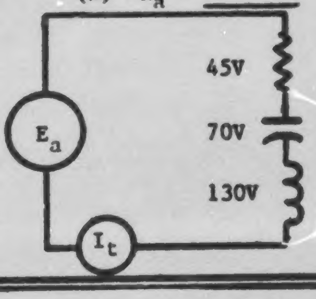
$$E_L = I_t \cdot X_L$$

Q-9 Determine the type of circuit, select the proper group of equations, and solve the following problems.

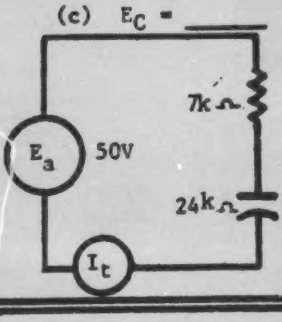
(a) E_R = ______



(b) E_a = ______



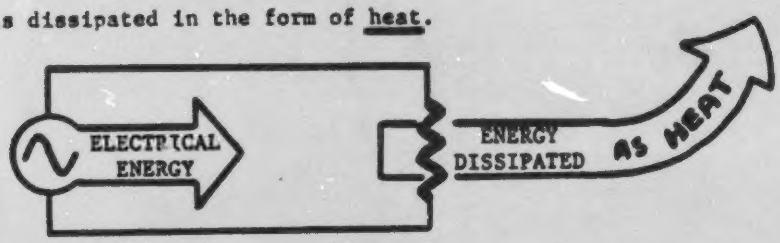
(c) E_C = ______



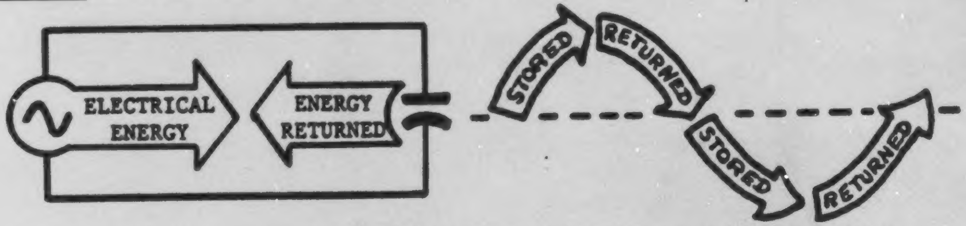
A-8
a. $Z = 25k\Omega$ $E_R = 21V$
$I_t = 3mA$ $E_C = 90V$
$E_L = 18V$
b. $Z = 65k\Omega$ $E_R = 120V$
$I_t = 2mA$ $E_L = 50V$
c. True

POWER IN REACTIVE CIRCUITS

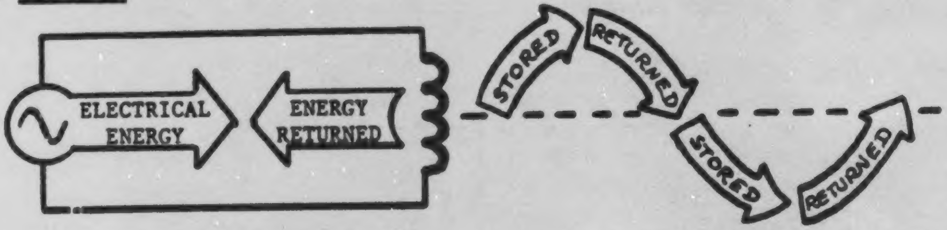
Electrical energy, delivered into a circuit containing a resistor, is dissipated in the form of heat.


ELECTRICAL ENERGY
ENERGY DISSIPATED
AS HEAT

Electrical energy, delivered into a circuit containing a capacitor, is NOT dissipated as heat. It is stored, for a moment, as a "charge" within the capacitor. When the capacitor "discharges", the energy is returned to the power source.


ELECTRICAL ENERGY
ENERGY RETURNED
STORED
RETURNED
STORED
RETURNED

Electrical energy, delivered into a circuit containing an inductor, is NOT dissipated as heat. It is stored, for a moment, as a magnetic field, surrounding the inductor. When the field "collapses", the energy is returned to the power source.


ELECTRICAL ENERGY
ENERGY RETURNED
STORED
RETURNED
STORED
RETURNED

Q-10
a. T-F Power is dissipated in the form of heat from a resistive component such as a resistor.
b. T-F A capacitor dissipates power in the form of heat.
c. T-F A capacitor "stores" power.
d. T-F An inductor "stores" power in the form of a magnetic field.
e. T-F Inductor power is "stored" when the field collapses.

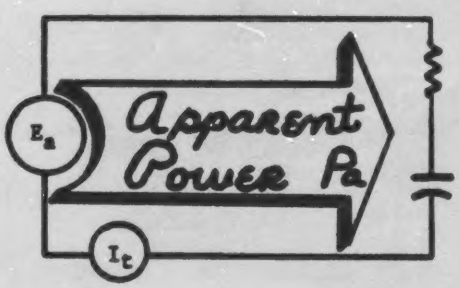
A-9
a. $Z = 40\Omega$
$I_t = 3A$
$E_R = 72V$

b. $E_a = 75V$

c. $Z = 25k\Omega$
$I_t = 2mA$
$E_C = 48V$

APPARENT POWER

The electrical energy delivered into any AC circuit is called the APPARENT POWER. (Symbol P_a) It is the product of the Applied Voltage (E_a), and the Total Current (I_t).



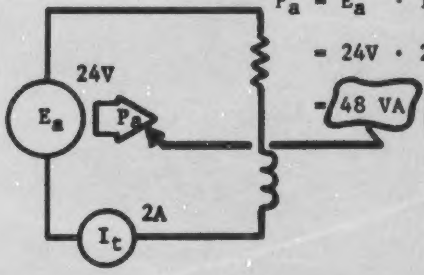
P_a

APPARENT POWER = APPLIED VOLTAGE × TOTAL CURRENT

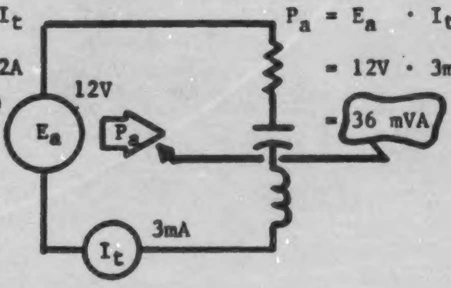
$$P_a = E_a \cdot I_t$$

The unit of measure for Apparent Power is the VOLT-AMPERE (Symbol VA). If the circuit current is in milli-amperes (mA), the Apparent Power calculation comes out in milli-volt-amperes (mVA).

EXAMPLES:



$P_a = E_a \cdot I_t$
$= 24V \cdot 2A$
$= 48\ VA$



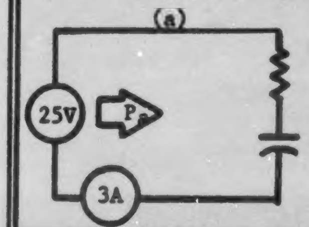
$P_a = E_a \cdot I_t$
$= 12V \cdot 3mA$
$= 36\ mVA$

Large amounts of electrical power, such as that required to operate radio or Radar equipment is given in KILO-VOLT-AMPERES (KVA).

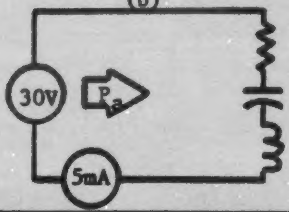
EXAMPLE: 400V at 50A = 2000 VA or 2 k VA

Q-11 Calculate the APPARENT POWER in the following circuits.

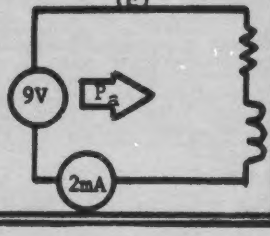
(a)



(b)



(c)



A-10
a. True....it is NOT returned.
b. False...it stores energy as a charge.
c. True...as a "charge".
d. True
e. False...it returns the power when the field collapses.

TRUE POWER

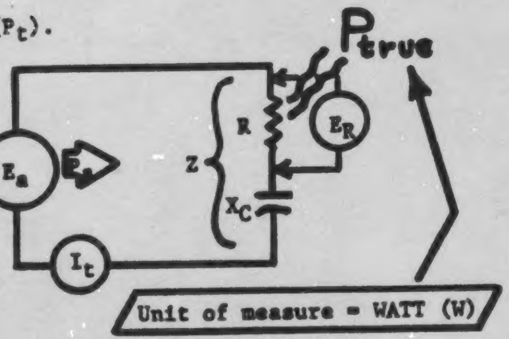
Power dissipated in the form of heat by circuit resistance, is called the TRUE POWER (Symbol P_t). It is only a part of the Apparent Power delivered into the circuit. The rest of the energy is "stored" by capacitors or inductors, and returned to the power source when they "discharge". Any of the power equations previously learned can be used to calculate the TRUE POWER (P_t).

True Power

$P_t = E_R \cdot I_t$

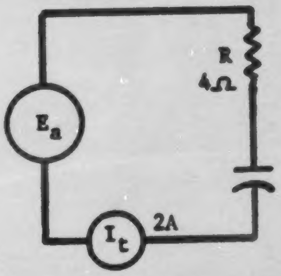
$P_t = \frac{E_R^2}{R}$

$P_t = I_t^2 \cdot R$



Unit of measure = WATT (W)

EXAMPLES:

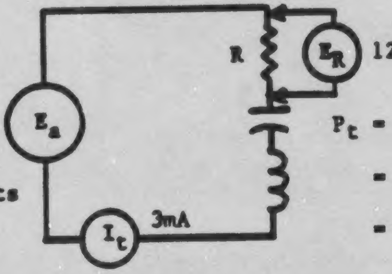


$P_t = I_t^2 \cdot R$

$= 2^2 \cdot 4$

$= 4 \cdot 4$

$=$ 16 Watts



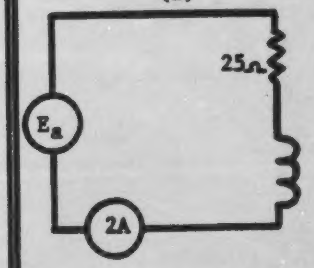
$P_t = E_R \cdot I_t$

$= 12 \cdot 3$

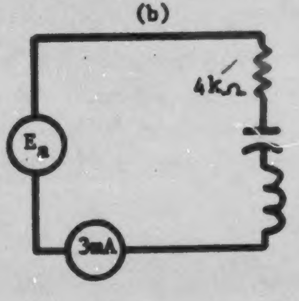
$=$ 36 mW

Q-12 Calculate the TRUE POWER in the following circuits.

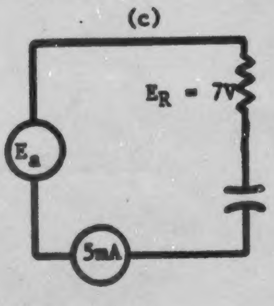
(a)



(b)



(c)



d. The "unit of measure" for True Power (P_t) is the _________.

e. T-F The "True Power" is dissipated by the resistive components.

A-11 a. 75 Volt Amperes b. 150 mVA c. 18 mVA

POWER FACTOR

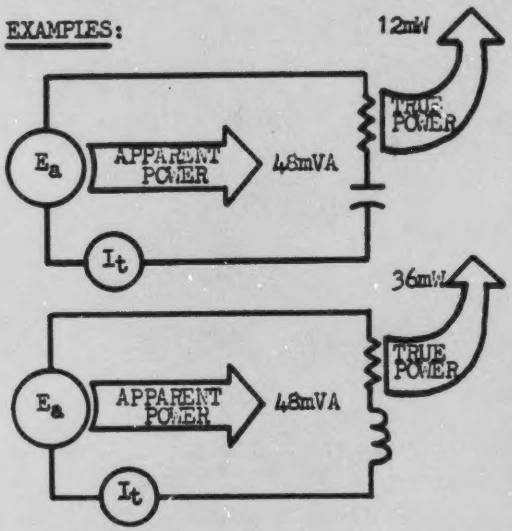
Electronic circuits often demand more electrical energy from a power source than they actually use or dissipate. This is because, reactive circuits contain power "dissipating" resistors, and power "returning" capacitors or inductors.

A comparison of the power demand by a circuit (Apparent Power), and the power actually used or dissipated (True Power), is called the circuit POWER FACTOR (Symbol PF).

$$\text{Power Factor} = \frac{\text{TRUE POWER}}{\text{APPARENT POWER}} \qquad \boxed{PF = \frac{P_t}{P_a}}$$

The POWER FACTOR (PF) has no unit of measure. It is simply a decimal or percentage number. It indicates how much of the power demanded by a circuit, is actually used or dissipated by the resistor.

EXAMPLES:



$$PF = \frac{\text{TRUE POWER}}{\text{APPARENT POWER}} = \frac{12\text{mW}}{48\text{mW}} = .25 \text{ or } 25\%$$

$$PF = \frac{\text{TRUE POWER}}{\text{APPARENT POWER}} = \frac{36\text{mW}}{48\text{mW}} = .75 \text{ or } 75\%$$

In the RL circuit above, a greater percentage of the "input" Apparent Power (P_a) is dissipated in the form of heat.

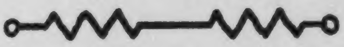
Q-13 a. The number which indicates what percentage of the Apparent Power is actually dissipated, is called the _____ _____.

A-12
a. 100W
b. 36 mW
c. 35 mW
d. Watt
e. True...in the form of heat.

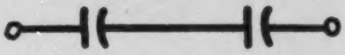
OPERATING CHARACTERISTIC

Alternating current circuits are spoken of as "operating" or "acting": RESISTIVELY, CAPACITIVELY, or INDUCTIVELY. It depends upon the type of circuit, and the components used.

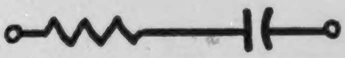
This CIRCUIT......................is OPERATING....



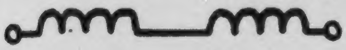
Purely resistive or resistively



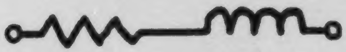
Purely capacitive



Capacitively



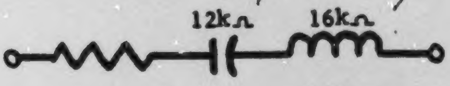
Purely inductive



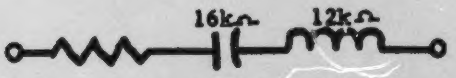
Inductively

In the case of Series RCL Circuits, the oppositions of the capacitor and inductor determine how the circuit will operate.

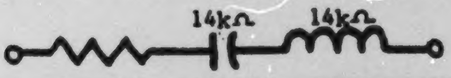
This CIRCUIT......................is OPERATING....



Inductively

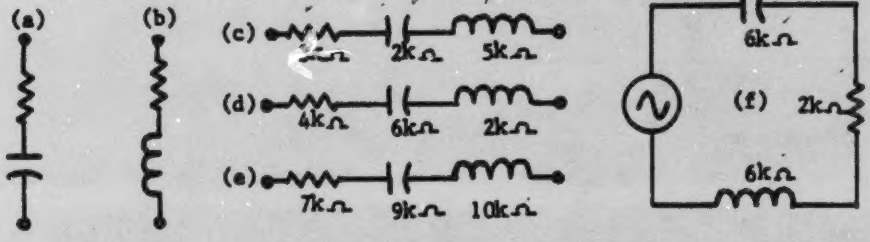


Capacitively



Resistively

Q-14 How are the following circuits OPERATING or ACTING?


(a)
(b)
(c)
2kΩ
5kΩ
(d)
4kΩ
6kΩ
2kΩ
(e)
7kΩ
9kΩ
10kΩ
6kΩ
(f)
2kΩ
6kΩ

A-13

a. Power Factor (PF)

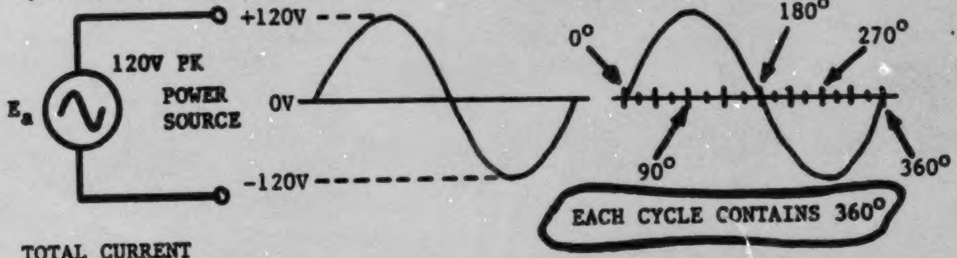
PHASE ANGLE

The "angular" difference between the Applied Voltage (E_a), and the Total Current (I_t), is called the PHASE ANGLE (Symbol θ).

One of the important jobs of Reactive Circuits, is to develop a particular "phase difference" between the circuit voltage and current.

APPLIED VOLTAGE

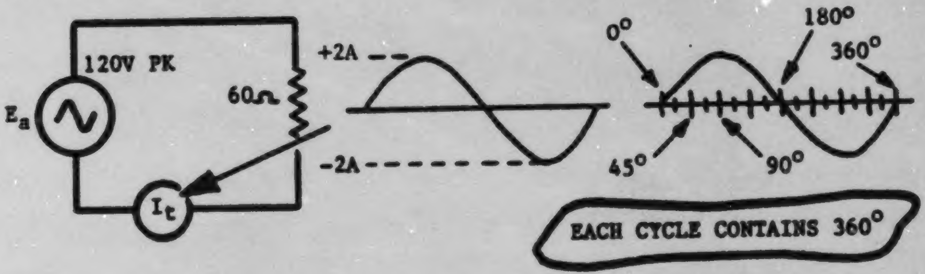
The Applied Voltage (E_a), is an alternating voltage (sine wave or cycle), supplied by some type of power source.



+120V
120V PK
POWER SOURCE
E_a
0V
-120V
0°
180°
270°
90°
360°
EACH CYCLE CONTAINS 360°

TOTAL CURRENT

The Total Current (I_t), is the alternating current resulting from the electromotive force of the Applied Voltage (E_a).



120V PK
E_a
60Ω
I_t
+2A
-2A
0°
180°
360°
45°
90°
EACH CYCLE CONTAINS 360°

As the Applied Voltage (E_a) increases and decreases, the Total Current (I_t) increases and decreases at the same time. When E_a is at 0V, the Total Current is at 0A. When the Applied Voltage is at 120V, the Total Current is at its peak of 2A, and so on.....

Q-15 a. The angular difference between the Applied Voltage (E_a), and the Total Current (I_t) is called the _________ __________.

b. T-F The Applied Voltage (E_a) comes from the "power source".

c. T-F Each cycle of the Total Current (I_t) contains 360 degrees.

d. The symbol for "Phase Angle" is ______.

A-14

a. Capacitively

b. Inductively

c. Inductively (X_L larger than X_C)

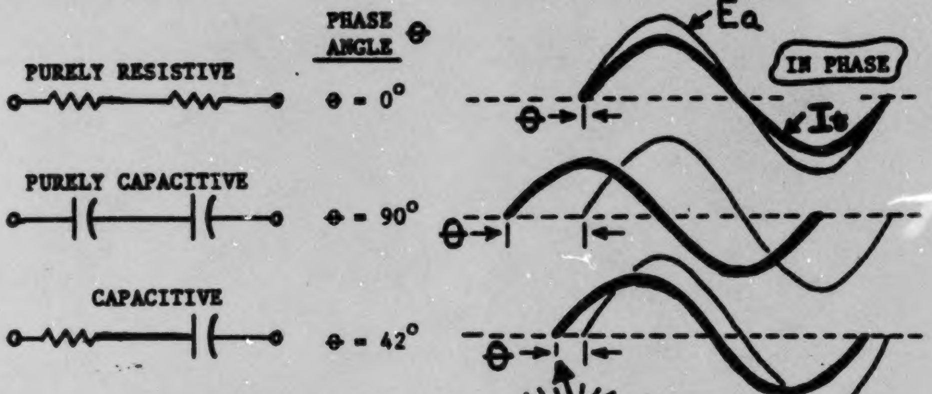
d. Capacitively (X_C larger than X_L)

e. Inductively (X_L larger than X_C)

f. Resistively (X_C and X_L equal)

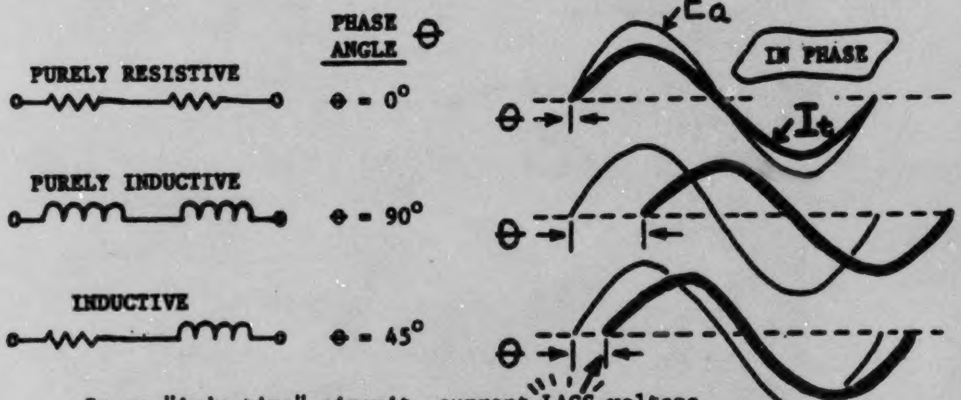
PHASE ANGLE (cont)

The number of degrees difference between the Applied Voltage (E_a), and the Total Current (I_t), depends upon the type of circuit.


PHASE ANGLE θ
PURELY RESISTIVE
θ = 0°
PURELY CAPACITIVE
θ = 90°
CAPACITIVE
θ = 42°
Ea
IN PHASE
It
θ
θ
θ

In a "capacitive" circuit, current LEADS voltage.

The exact angle between voltage and current, depends upon the opposition of the resistor and capacitor.


PHASE ANGLE θ
PURELY RESISTIVE
θ = 0°
PURELY INDUCTIVE
θ = 90°
INDUCTIVE
θ = 45°
Ea
IN PHASE
It
θ
θ
θ

In an "inductive" circuit, current LAGS voltage.

The exact angle between voltage and current, depends upon the opposition of the resistor and inductor.

Q-16 a. T-F In a "resistive" circuit, the voltage and current are "in phase".

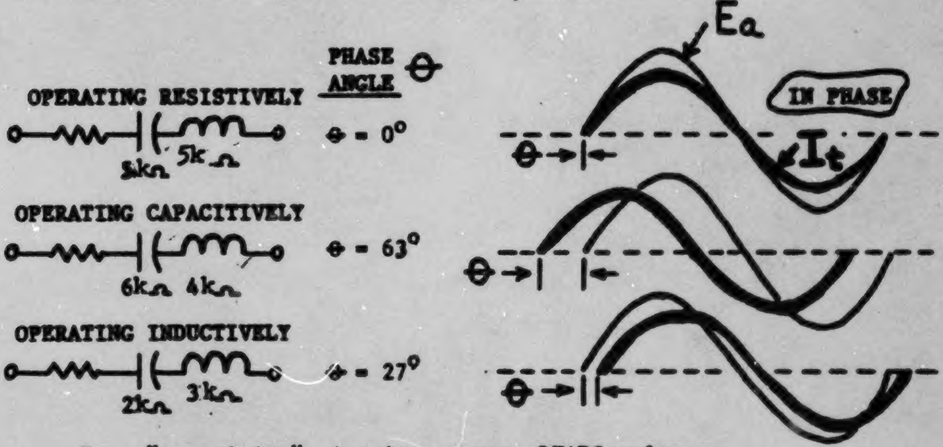
b. T-F In "capacitive" circuits, current "leads" voltage.

c. T-F In "inductive" circuits, voltage "leads" current.

A-15
- a. Phase Angle....symbol (θ)
- b. True....it is a "sine wave" voltage, supplied from some type of power source such as a generator.
- c. True
- d. (θ)...actually, it is the Greek letter "theta".

PHASE ANGLE (cont)

The PHASE ANGLE (θ), in a Series RCL circuit, depends upon how the circuit is "operating". The opposition of the capacitor and inductor determines how the circuit will "operate".

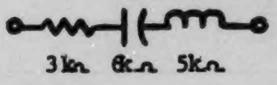

PHASE ANGLE θ
OPERATING RESISTIVELY
5kΩ 5kΩ
θ = 0°
Ea
IN PHASE
It
θ
OPERATING CAPACITIVELY
6kΩ 4kΩ
θ = 63°
θ
OPERATING INDUCTIVELY
2kΩ 3kΩ
θ = 27°
θ

In a "capacitive" circuit, current LEADS voltage. In an "inductive" circuit, current LAGS voltage. In an RCL circuit, when the opposition of the capacitor and inductor is the same, the circuit is operating "resistively", and the current is IN PHASE with the voltage.

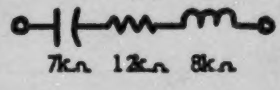
The exact number of degrees in the PHASE ANGLE (θ), is determined by the oppositions of the various components.

Q-17 How will the following circuits "operate"?

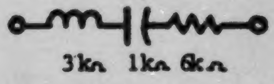
(a)



(b)

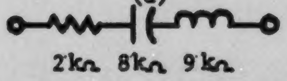

7kΩ 12kΩ 8kΩ

(c)

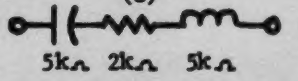


Will the Total Current "lead" or "lag" or be "in phase" with the Applied Voltage, in the following circuits.

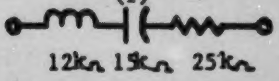
(d)



(e)



(f)


12kΩ 15kΩ 25kΩ

A-16 a. True....voltage and current "rise and fall" together.
b. True....it could also be said that voltage "lags" current.
c. True....saying the voltage "leads" current, is the same as saying current "lags" voltage.

PHASE ANGLE (cont)

The **PHASE ANGLE** (θ), for any reactive circuit, can be determined thru the use of a Trigonometry Table. (The Electronics Handbook KEP-110 has such a table.) The only columns of interest now, are the "cosine" (cos) column, and the "degree" (deg) column.

To obtain some practice using these two columns, follow along in the "trig" table with each of these examples:

USE THE HEADINGS AT THE TOP OF THE PAGE, AND READ DOWN THE COLUMNS.

COSINE NUMBER (cosine column)	θ PHASE ANGLE (degree column)
.9994	2.0°
.9986	3.0°
.9962	5.0°
.9900	8.1°
.9833	10.5°
.9673	14.7°
.9164	23.6°
.8755	28.9°
.8290	34.0°
.7760	39.1°
.7193	44.0°
.7071	45.0°

At 45°, the table now "folds back upon itself", and is read backwards!

USE THE HEADINGS AT THE BOTTOM OF THE PAGE, AND READ UP THE COLUMNS.

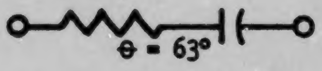
.7009	45.5°
.6997	45.6°
.6947	46.0°
.6934	46.1°
.6691	48.0°
.6521	49.3°
.6225	51.5°
.5934	53.6°
.5314	57.9°
.4894	60.7°
.3600	68.9°
.2351	76.4°
.1478	81.5°
.0505	87.1°

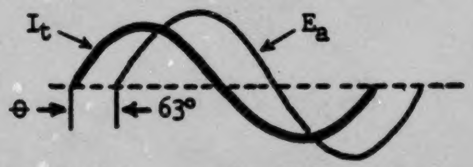
Q-18 Look-up the Phase Angle (θ), for each "cosine number" shown.

a.	.9969	d.	.6807	g.	.6704
b.	.9198	e.	.3518	h.	.9664
c.	.7157	f.	.1736	i.	.4772

A-17 a. Capacitively (X_C larger)
b. Inductively (X_L larger)
c. Inductively (X_L larger)
d. Current will "lag" (Inductively)
e. Current "in phase" (Resistively)
f. Current will "lead" (Capacitive)

PHASE ANGLE (cont)



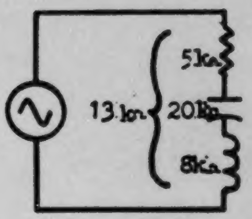


The PHASE ANGLE (θ), is determined by use of a Trigonometry Table. Several equations may be used to calculate the "cosine number", which is then used to look-up the Phase Angle (θ).

$$\text{cosine} = \frac{\text{R (Resistance)}}{\text{Z (Impedance)}}$$

$$\text{cosine} = \frac{E_R \text{ (Resistor Voltage)}}{E_a \text{ (Applied Voltage)}}$$

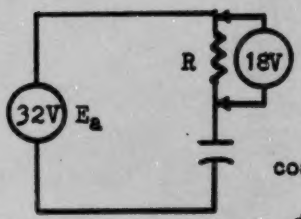
EXAMPLES:



$$\cos = \frac{R}{Z} = \frac{5\,k\Omega}{13\,k\Omega}$$

$$\cos = .3846$$

$$\theta = 67.4^\circ$$



$$\cos = \frac{E_R}{E_a} = \frac{18V}{32V}$$

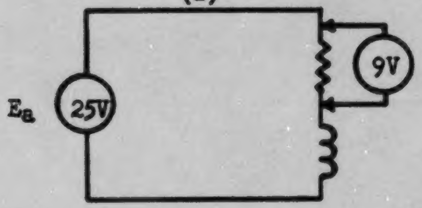
$$\cos = .5625$$

$$\theta = 55.8^\circ$$

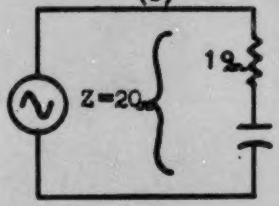
Use whichever equation is the easiest & most convenient at the time.

Q-19 Determine the Phase Angle θ in the following circuits.

(a)



(b)

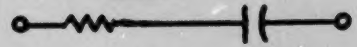


A-18

a. 4.5°
b. 23.1°
c. 44.3°
d. 47.1°
e. 69.4°
f. 80.0°
g. 47.9°
h. 14.9°
i. 61.5°

EQUATION SUMMARY

SERIES RC



$$Z = \sqrt{R^2 + X_C^2}$$

$$I_t = \frac{E_a}{Z}$$

$$E_R = I_t \cdot R$$

$$E_C = I_t \cdot X_C$$

$$E_a = \sqrt{E_R^2 + E_C^2}$$

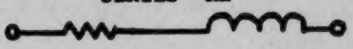
$$P_t = \left(I_t^2 \cdot R\right) = \left(\frac{E_R^2}{R}\right) = \left(E_R \cdot I_t\right)$$

$$P_a = \left(E_a \cdot I_t\right) = \left(I_t^2 \cdot Z\right) = \left(\frac{E_a^2}{Z}\right)$$

$$\text{cosine} = \frac{R}{Z} \text{ or } \frac{E_R}{E_a}$$

θ = Look-up "cos" in Trig Table

SERIES RL



$$Z = \sqrt{R^2 + X_L^2}$$

$$I_t = \frac{E_a}{Z}$$

$$E_R = I_t \cdot R$$

$$E_L = I_t \cdot X_L$$

$$E_a = \sqrt{E_R^2 + E_L^2}$$

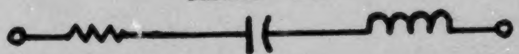
$$P_t = \left(I_t^2 \cdot R\right) = \left(\frac{E_R^2}{R}\right) = \left(E_R \cdot I_t\right)$$

$$P_a = \left(E_a \cdot I_t\right) = \left(I_t^2 \cdot Z\right) = \left(\frac{E_a^2}{Z}\right)$$

$$\text{cosine} = \frac{R}{Z} \text{ or } \frac{E_R}{E_a}$$

θ = Look-up "cos" in Trig Table

SERIES RCL



$$Z = \sqrt{R^2 + (X_C - X_L)^2} \qquad Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$I_t = \frac{E_a}{Z} \qquad E_R = I_t \cdot R \qquad E_C = I_t \cdot X_C \qquad E_L = I_t \cdot X_L$$

$$E_a = \sqrt{E_R^2 + (E_C - E_L)^2} \qquad E_a = \sqrt{E_R^2 + (E_L - E_C)^2}$$

$$P_t = \left(I_t^2 \cdot R\right) = \left(\frac{E_R^2}{R}\right) = \left(E_R \cdot I_t\right) \qquad P_a = \left(E_a \cdot I_t\right) = \left(I_t^2 \cdot Z\right) = \left(\frac{E_a^2}{Z}\right)$$

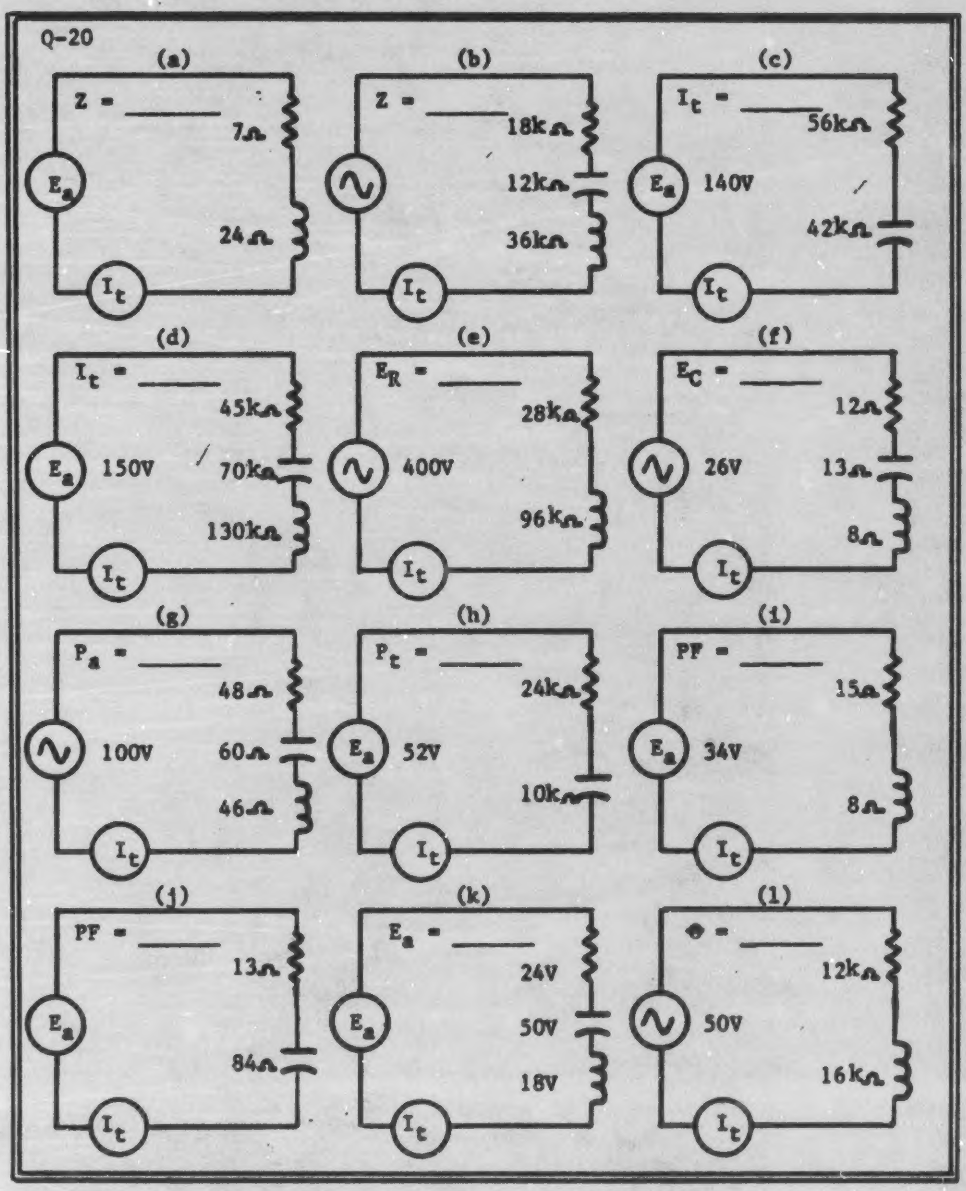
$$\text{cosine} = \frac{R}{Z} \text{ or } \frac{E_R}{E_a}$$

θ = Look-up "cos" in Trig Table

A-19 a. cosine = .3600 0 = 68.9° b. cos = .9500 0 = 18.2°

REACTIVE CIRCUIT PROBLEMS

Determine the type of circuit, select the proper group of equations from the previous EQUATION SUMMARY, and solve the following Series Reactive Circuit problems. Answers listed under A-20

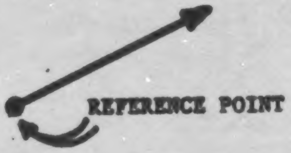

Q-20
(a)
Z = ______
7Ω
E_a
24Ω
I_t
(b)
Z = ______
18kΩ
12kΩ
36kΩ
I_t
(c)
I_t = ______
56kΩ
E_a
140V
42kΩ
I_t
(d)
I_t = ______
45kΩ
E_a
150V
70kΩ
130kΩ
I_t
(e)
E_R = ______
28kΩ
400V
96kΩ
I_t
(f)
E_C = ______
12Ω
26V
13Ω
8Ω
I_t
(g)
P_a = ______
48Ω
100V
60Ω
46Ω
I_t
(h)
P_t = ______
24kΩ
E_a
52V
10kΩ
I_t
(i)
PF = ______
15Ω
E_a
34V
8Ω
I_t
(j)
PF = ______
13Ω
E_a
84Ω
I_t
(k)
E_a = ______
24V
E_a
50V
18V
I_t
(l)
θ = ______
12kΩ
50V
16kΩ
I_t

VECTOR DIAGRAMS (Series Reactive Circuits)

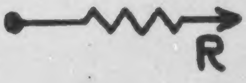
Another method, for examining the performance of Reactive Circuits, is thru the use of VECTOR DIAGRAMS. Although they may appear hard to understand at first, they do simplify and clarify the operation of many electronic circuits.

A VECTOR is a line, having a particular length, and an arrow on one end indicating direction. The starting point of the vector is called the "reference point".

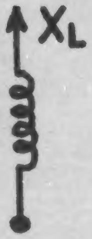
Vector



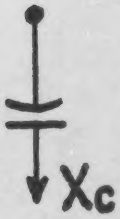
The length of the vector, will represent the amount of Ohms, Volts, or Amps at a particular point in the circuit. The direction of the vector, depends upon what is being represented.



The opposition of a resistor (R), is always drawn on the horizontal, to the right of the reference point.



The opposition of an inductor (X_L), is always drawn straight "up" from the reference point.



The opposition of a capacitor (X_C), is always drawn straight "down" from the reference point.

REMEMBER: R horizontal..... X_L up ..... X_C down.

Q-21
a. A line, having a particular "length", and "direction", is called a ________________.
b. T-F. The length of the line represents "what is being represented" by the vector.
c. T-F. The direction of the vector, represents "what is being represented".
d. T-F. The length of a vector, represents the "amount".

A-20

a. $Z = 25$

b. $Z = 30k$

c. $I_t = 2mA$

d. $I_t = 2mA$

e. $E_R = 112V$

f. $E_C = 26V$

g. $P_a = 200VA$

h. $P_t = 96mW$

i. $PF = .8823$

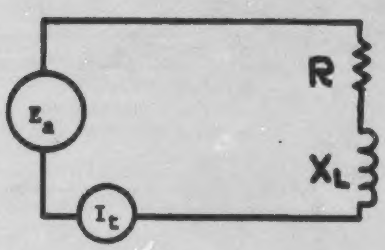
j. $PF = .1529$

k. $E_a = 40V$

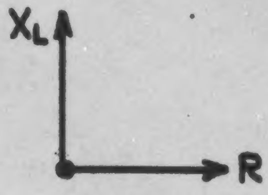
l. $\theta = 53.1^\circ$

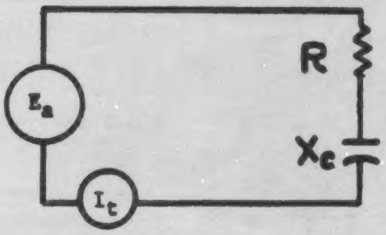
VECTOR DIAGRAMS (cont)

A vector diagram can be used to represent the oppositions, in a Series Reactive Circuit. These circuits, and their vector diagrams, are shown below. Remember: R horizontal.... X_L up..... X_C down.....

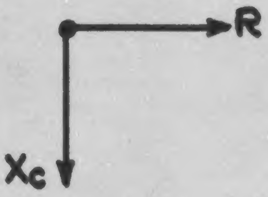


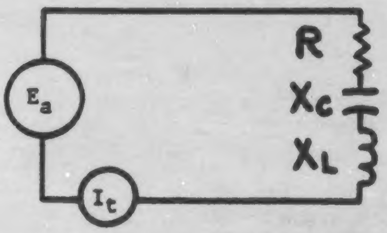
SERIES RL



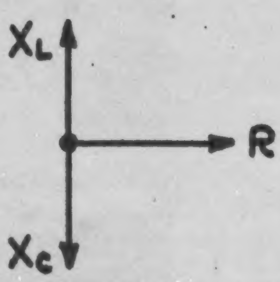


SERIES RC

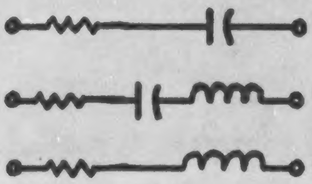




SERIES RCL



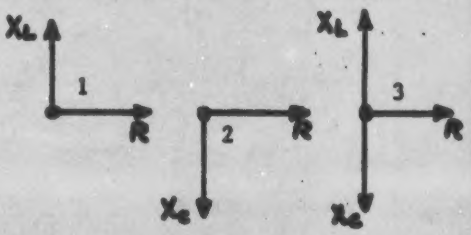
Q-22 Match the following circuits with their proper vector diagram.



a = ___

b = ___

c = ___

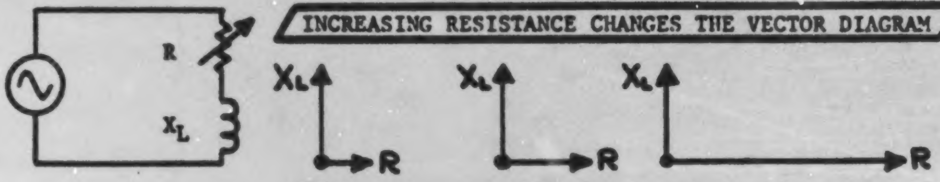

X_L
1
R
2
R
X_C
X_L
3
R
X_C

A-21
- a. vector
- b. False....the length of a vector, represents the amount.
- c. True.....opposition of a resistor,(horizontal)...opposition of a capacitor (straight down)...opposition of an inductor (up).
- d. True...the greater the opposition, the longer the vector.

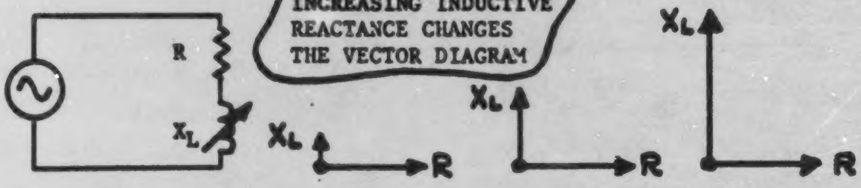
VECTOR DIAGRAMS (cont)

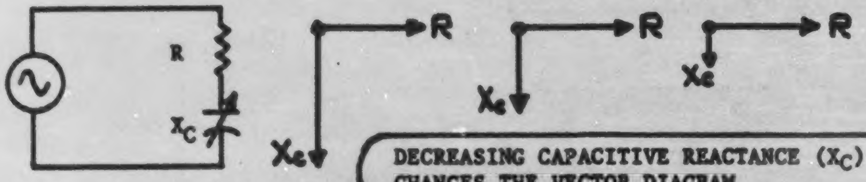
The type of circuit, RC RL or RCL, can be determined by simply drawing the vector diagram, instead of the actual circuit diagram. The direction of the vector represents the type of opposition. Recall also....the physical length of the vector is "how much" opposition.

INCREASING RESISTANCE CHANGES THE VECTOR DIAGRAM


R
X_L
X_L
R
X_L
R
X_L
R

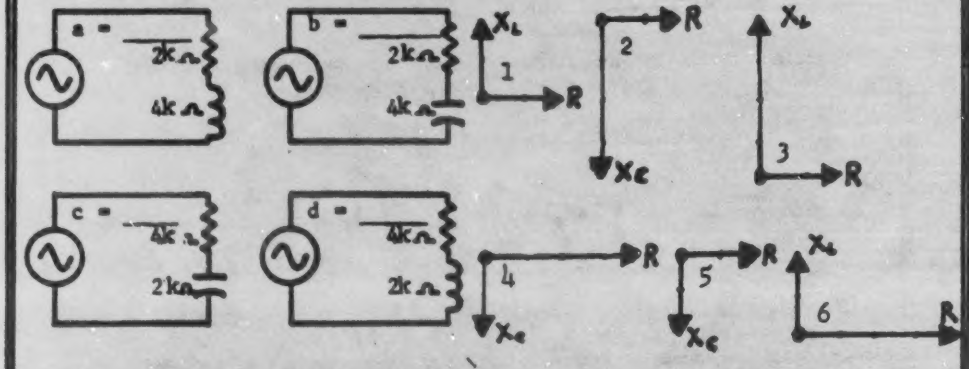
INCREASING INDUCTIVE REACTANCE CHANGES THE VECTOR DIAGRAM


R
X_L
X_L
R
X_L
R
X_L
R


R
X_C
R
X_C
R
X_C
R
X_C

DECREASING CAPACITIVE REACTANCE (X_C) CHANGES THE VECTOR DIAGRAM

Q-23 Match circuits with vectors.


a -
2kΩ
4kΩ
b -
2kΩ
4kΩ
c -
4kΩ
2kΩ
d -
4kΩ
2kΩ
1
X_L
R
2
R
X_C
3
X_L
R
4
R
X_C
5
R
X_C
6
X_L
R

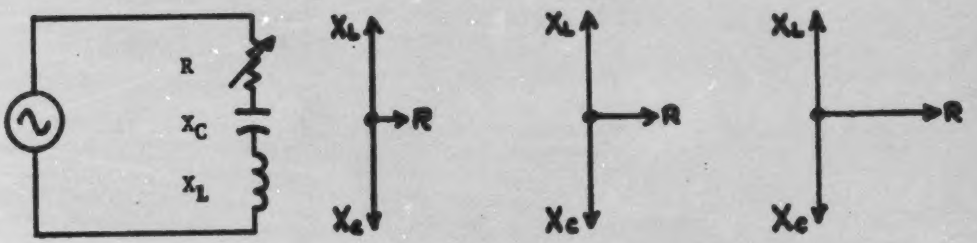
A-22

a = 2 b = 3 c = 1

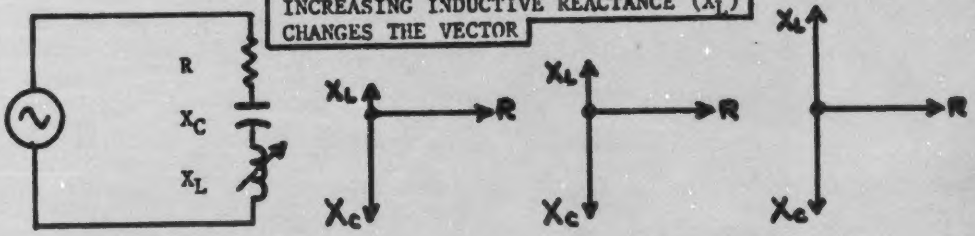
VECTOR DIAGRAMS (cont)

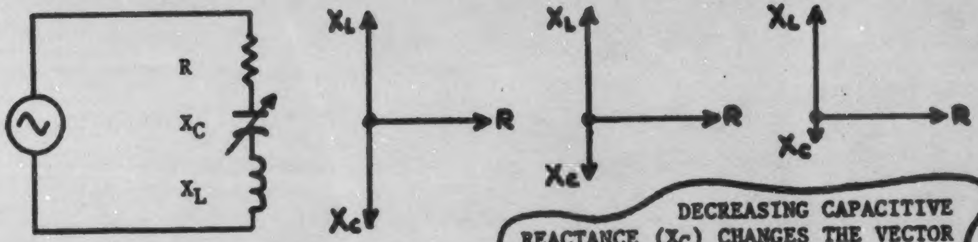
Series RCL circuits, contain all three vectors: R, X_C, and X_L. Remember, the direction of a vector represents the type of opposition. The length of the vector is determined by the amount of opposition.

INCREASING RESISTANCE (R) CHANGES THE VECTOR


R
X_C
X_L
X_L
R
X_C
X_L
R
X_C
X_L
R
X_C

INCREASING INDUCTIVE REACTANCE (X_L) CHANGES THE VECTOR


R
X_C
X_L
X_L
R
X_C
X_L
R
X_C
X_L
R
X_C

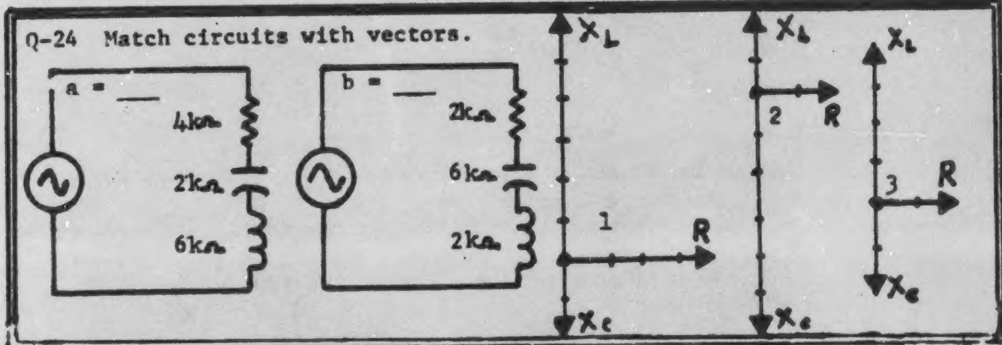

R
X_C
X_L
X_L
R
X_C
X_L
R
X_C
X_L
R
X_C

DECREASING CAPACITIVE REACTANCE (X_C) CHANGES THE VECTOR

Q-24 Match circuits with vectors.

a = ____

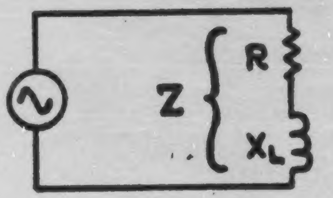
b = ____

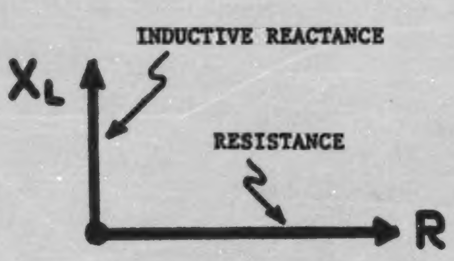

4kΩ
2kΩ
6kΩ
2kΩ
6kΩ
2kΩ
X_L
1
R
X_C
X_L
2
R
X_C
X_L
3
R
X_C

A-23 a = 3 b = 2 c = 4 d = 6

IMPEDANCE VECTOR DIAGRAM

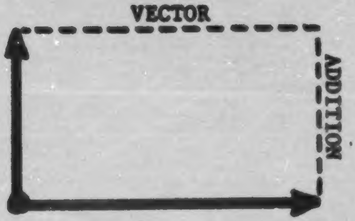
The total opposition (Impedance) of a Reactive Circuit, is also represented by a vector. The IMPEDANCE (Z) vector is obtained thru "vector addition".




INDUCTIVE REACTANCE
X_L
RESISTANCE
R

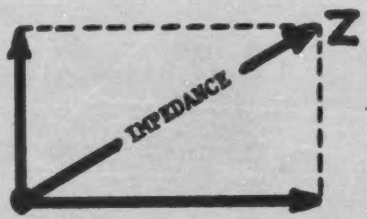
VECTOR ADDITION

Parallel "dotted" lines

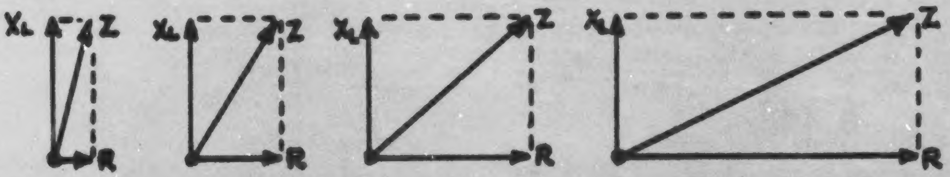

VECTOR
ADDITION

VECTOR SUM

The Impedance (Z) vector


Z
IMPEDANCE

The length of the IMPEDANCE (Z) vector, represents the amount of total opposition in the circuit. Notice how the total opposition (length of Z vector) increases, with an increase in resistance (R).


X_L
Z
R
X_L
Z
R
X_L
Z
R
X_L
Z
R

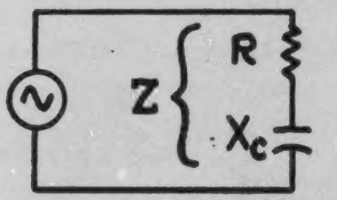
Q-25 a. The "impedance vector" is obtained thru _______ ________.
b. Increasing the opposition of the resistance, causes the total opposition (Impedance Z) to ________(inc or dec).
c. Increasing the opposition of an inductor (X_L), would cause the total opposition (Impedance Z) to ________(inc or dec).
NOTE: Look at the angle between R and Z. It may be important.

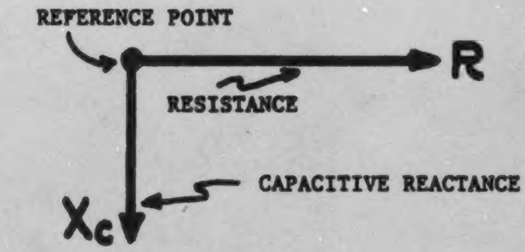
A-24

a = 1 b = 2

IMPEDANCE VECTOR DIAGRAMS (cont)

The total opposition (Impedance) of an RC Reactive Circuit, is also represented by a vector. The IMPEDANCE (Z) vector is obtained thru "vector addition".



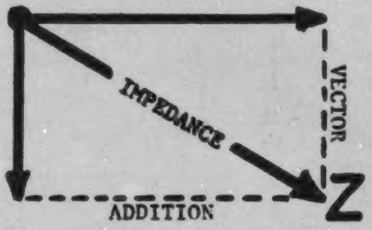

REFERENCE POINT
R
RESISTANCE
CAPACITIVE REACTANCE
X_C

VECTOR ADDITION

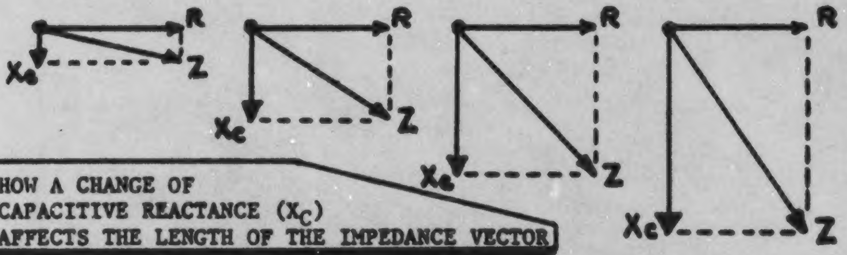
Parallel "dotted" lines

VECTOR SUM

The Impedance (Z) vector


IMPEDANCE
VECTOR
ADDITION
Z

The length of the IMPEDANCE (Z) vector, represents the amount of total opposition in the circuit. Notice how the total opposition (length of Z vector) increases, with an increase of Capacitive Reactance (X_C).


R
Z
X_C
R
Z
X_C
R
Z
X_C
R
Z
X_C

HOW A CHANGE OF
CAPACITIVE REACTANCE (X_C)
AFFECTS THE LENGTH OF THE IMPEDANCE VECTOR

Q-26
a. The Impedance vector is obtained thru ________ ___________.
b. The Impedance vector is called the _____________ sum.
c. T-F The "starting point" for vector diagrams is called the Reference Point.
d. What would increasing the length of the "resistance R" vector do to the total opposition (length of the Z vector)__________ (inc-dec)
e. T-F Frequency affects X_C.

NOTE: There's that angle again....the one between R and Z ? ? ? ? ? ? ?

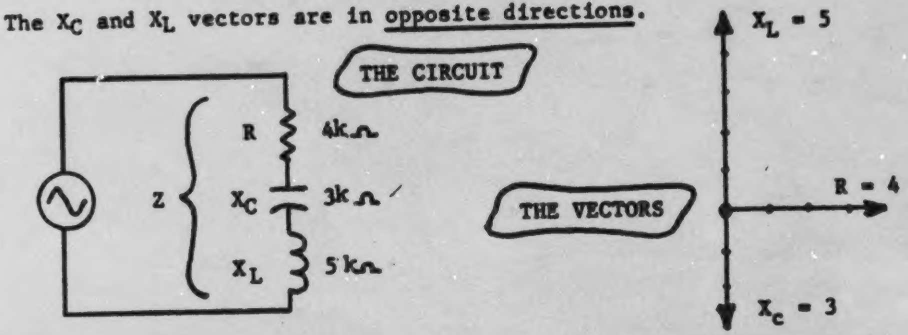
A-25 a. Vector Addition
b. Increase....if the R vector is longer, the Z vector is also.
c. Increase....if the X_L vector is drawn longer (more opposition), the resulting Z vector will also be longer.
NOTE: Wonder what angle that is? Could it be the ________ ________?

IMPEDANCE VECTOR DIAGRAMS (cont)

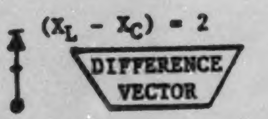
The total opposition (Impedance) of an RCL circuit, is also represented by a vector. The IMPEDANCE (Z) vector is obtained thru "vector addition", but there is one step to be accomplished first.

THE DIFFERENCE VECTOR

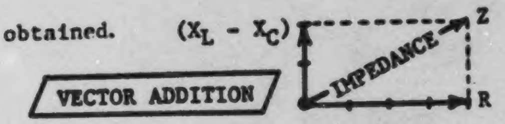
In RCL circuits, all three vectors (R, X_C and X_L) are present. The X_C and X_L vectors are in opposite directions.


THE CIRCUIT
R
4kΩ
Z
X_C
3kΩ
X_L
5kΩ
THE VECTORS
X_L = 5
R = 4
X_c = 3

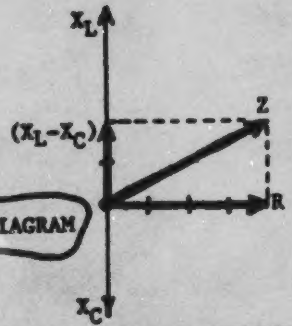
Because X_C and X_L are in opposite directions, thev must be subtracted, and a "difference vector" obtained.


$(X_L - X_C) = 2$
DIFFERENCE VECTOR

The "difference vector" is then added to the "resistance vector", and the "vector sum" obtained.


$(X_L - X_C)$
Z
IMPEDANCE
R
VECTOR ADDITION

This then, is the complete vector diagram, for an RCL circuit, operating INDUCTIVELY. (X_L greater than X_C)


COMPLETE VECTOR DIAGRAM
X_L
Z
(X_L-X_C)
R
X_C

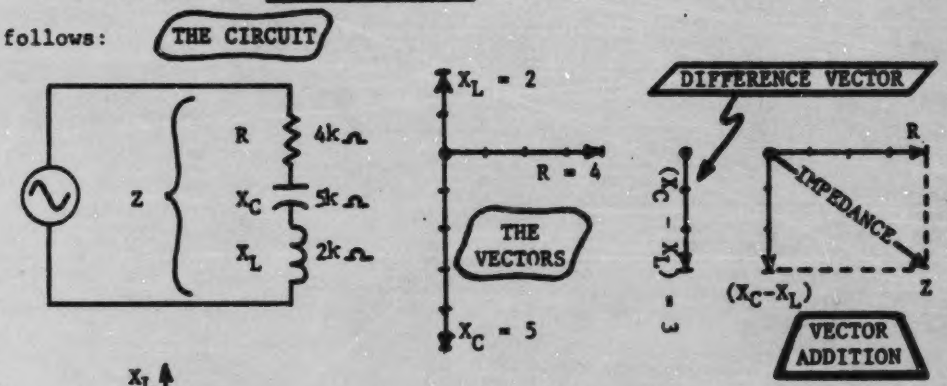
Q-27 a. In Series RCL circuits, the ____________ vector must be determined "first".
b. The "impedance" vector is obtained thru ________ ________.
c. Increasing the resistance (R vector) would ________ Impedance. (inc-dec)
NOTE: There's that angle again, between R and Z!

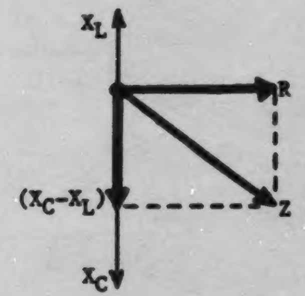
A-26 a. vector addition
b. vector
c. True
d. Increase....increasing either opposition, increases the total.
e. True....if frequency increases, X_C decreases $X_C\downarrow = \dfrac{1}{2\pi f\uparrow C}$

NOTE: Which angle? The one between R and Z!

IMPEDANCE VECTOR DIAGRAMS (cont)

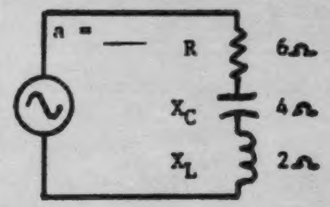
In an RCL circuit operating CAPACITIVELY (X_C larger than X_L), the vector representing total opposition (Impedance) would be developed as follows:

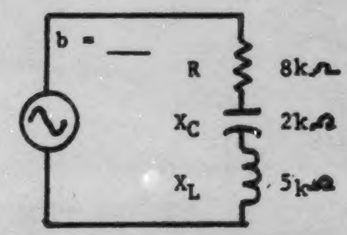

THE CIRCUIT
Z
R
4k Ω
X_C
5k Ω
X_L
2k Ω
X_L = 2
R = 4
THE VECTORS
X_C = 5
DIFFERENCE VECTOR
$(X_C - X_L)$ = 3
R
IMPEDANCE
(X_C-X_L)
Z
VECTOR ADDITION

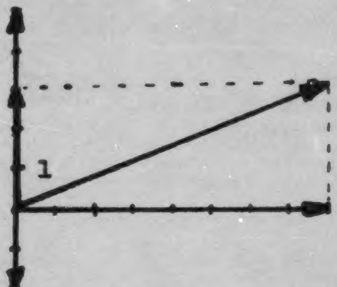

X_L
R
(X_C-X_L)
Z
X_C

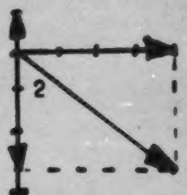
This is the completed vector diagram for (X_C larger than X_L) an RCL Circuit, operating CAPACITIVELY.

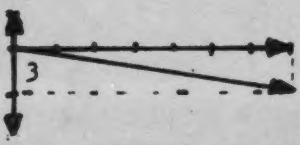
Q-28 Match the circuits with the proper IMPEDANCE VECTOR DIAGRAM.

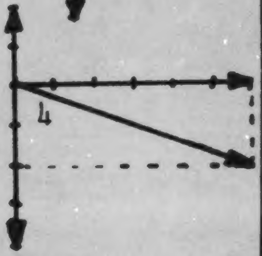

a = ___
R
6 Ω
X_C
4 Ω
X_L
2 Ω


b = ___
R
8k Ω
X_C
2k Ω
X_L
5k Ω









A-27

a. difference vector

b. vector addition.....only this time it is the vector addition of the Resistance R vector, and the "difference" vector.

c. Increase.

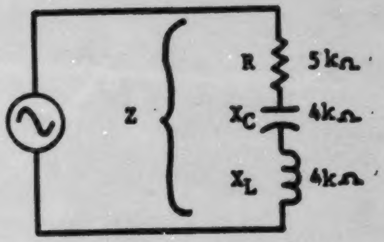
NOTE: That "angle" depends upon the length of R, and "difference" vectors

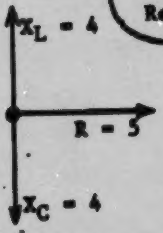
IMPEDANCE VECTOR DIAGRAMS (cont)

If an RCL Circuit is operating **RESISTIVELY** (X_C and X_L equal), the vector representing total opposition (Impedance) would be developed as follows:

THE VECTORS

THE CIRCUIT


Z
R
5kΩ
X_C
4kΩ
X_L
4kΩ

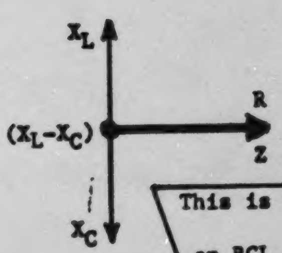


? THE DIFFERENCE VECTOR ?

There isn't any! $X_C - X_L = 0$
X_C and X_L cancel each other.
Result: NO DIFFERENCE VECTOR

VECTOR ADDITION

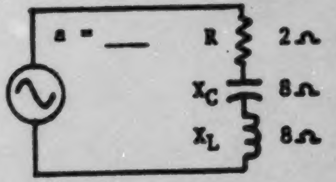
None to do!
With the cancellation of X_C & X_L, only Resistance remains, and (R) becomes the total opposition (Z).


X_L
$(X_L - X_C)$
R
Z
X_C

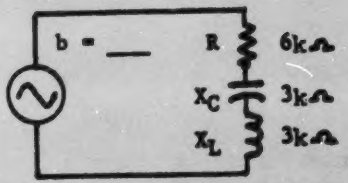
This is the completed vector diagram for (X_C and X_L equal) an RCL circuit, operating RESISTIVELY.

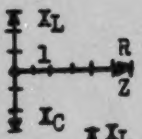
Q-29 Match the circuits with their proper IMPEDANCE VECTOR DIAGRAM.

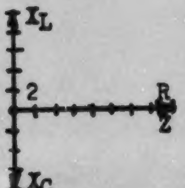
a = ___

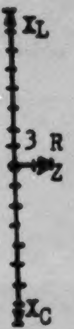

R
2Ω
X_C
8Ω
X_L
8Ω

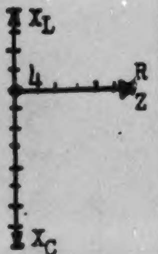
b = ___


R
6kΩ
X_C
3kΩ
X_L
3kΩ









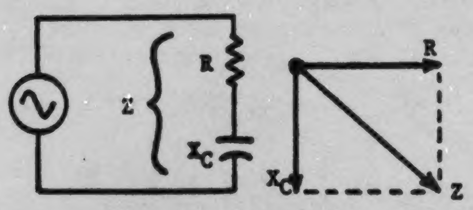
221

A-28

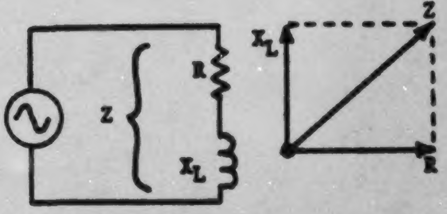
a = 4 b = 1

IMPEDANCE VECTOR DIAGRAMS (cont)

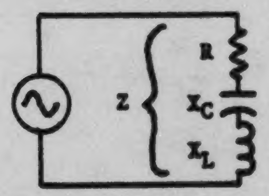
The following, is a summary of the five basic Impedance Vector Diagrams, for Series Reactive Circuits.



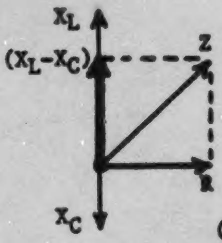
SERIES RC CIRCUIT



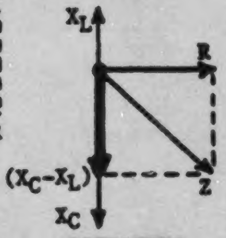
SERIES RL CIRCUIT



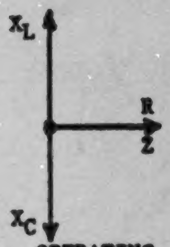
SERIES RCL CIRCUIT


X_L
(X_L-X_C)
Z
R
X_C

OPERATING INDUCTIVELY


X_L
R
(X_C-X_L)
Z
X_C

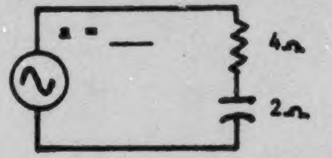
OPERATING CAPACITIVELY



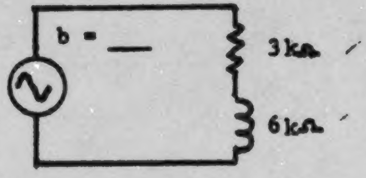
OPERATING RESISTIVELY

Q-30 Match the circuits with their proper IMPEDANCE VECTOR DIAGRAM.

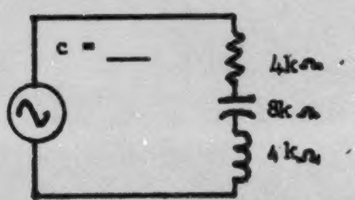
a = ___

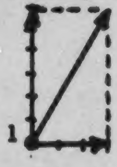


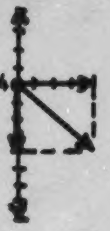
b = ___

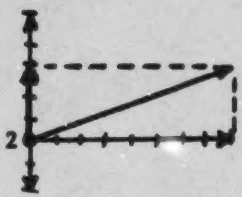


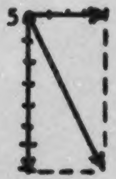
c = ___

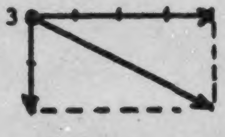


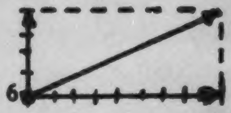
1


4


2


5


3


6


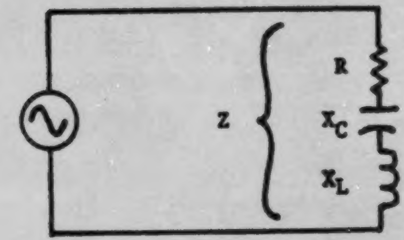
A-29 a = 3 b = 1

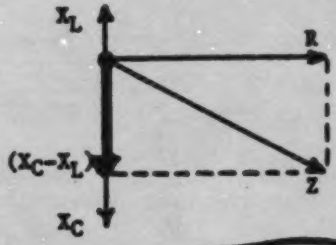
USING IMPEDANCE VECTORS

Impedance Vector Diagrams have several uses which will now be discussed.

1 FIRST

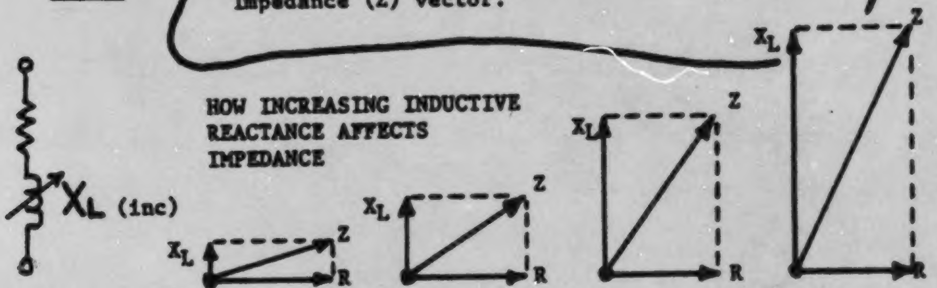
It is NOT necessary to draw the actual schematic diagram of the circuit. The Impedance Vector Diagram tells what type of circuit it is, and how it is operating.



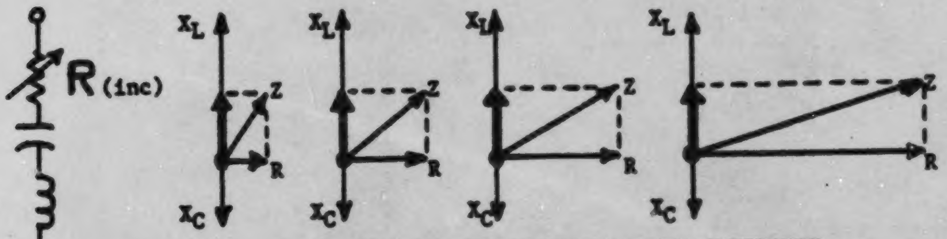


2 SECOND

It is easy to see, how changes in the amount of Resistance (R) or Reactance (X_C and X_L), affect the amount of Impedance (Z)....the length of the Impedance (Z) vector.



HOW INCREASING INDUCTIVE REACTANCE AFFECTS IMPEDANCE



HOW INCREASING RESISTANCE AFFECTS IMPEDANCE

Q-31 a. T-F Impedance vector diagrams can be drawn, instead of the actual schematic, to see how a circuit is "operating".

b. T-F It is easy to see the changes which occur in a circuit, when the impedance vectors are used, instead of equations.

NOTE: Soon that "angle" between R and Z, is comming up!

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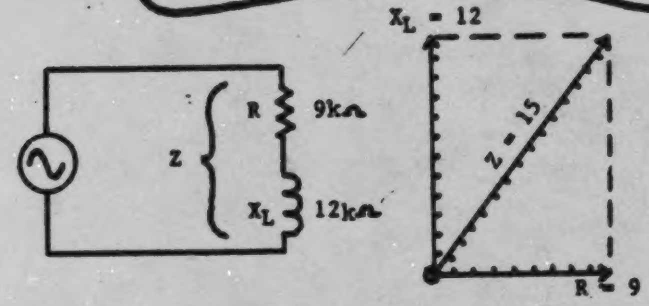
A-30 a = 3 b = 1 c = 4

USING IMPEDANCE VECTORS (cont)

3 THIRD

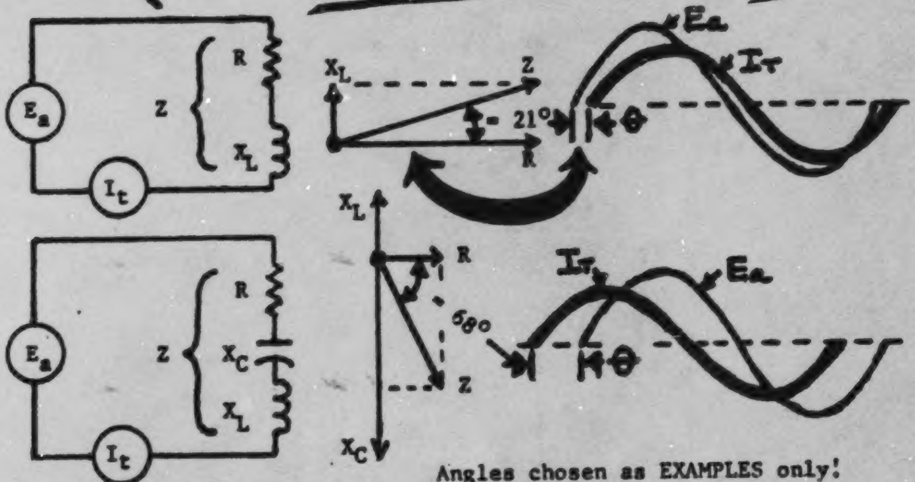
If the individual Resistance and Reactance vectors are drawn "to scale", the amount of Impedance (Z) can be measured directly from the drawing. This eliminates the need for mathematical calculations for Impedance (Z).



$$Z = \sqrt{R^2 + X_L^2}$$
$$= \sqrt{9^2 + 12^2}$$
$$= \sqrt{81 + 144}$$
$$= \sqrt{225}$$
$$Z = 15k\Omega$$

4 FOURTH

The PHASE ANGLE (θ) is present in the Impedance vector diagram. The angle between the Applied Voltage (E_a) and the Total Current (I_t), will be the SAME as the angle between Resistance (R) and Impedance (Z) vectors.



Angles chosen as EXAMPLES only!

Q-32 a. T-F The Impedance (Z), can be measured directly from an accurately drawn Impedance Vector Diagram.
b. T-F The Phase Angle (θ), can be measured directly from an accurately drawn Impedance Vector Diagram.
c. T-F The angle between R and Z, has the same number of degrees as the Phase Angle (θ).

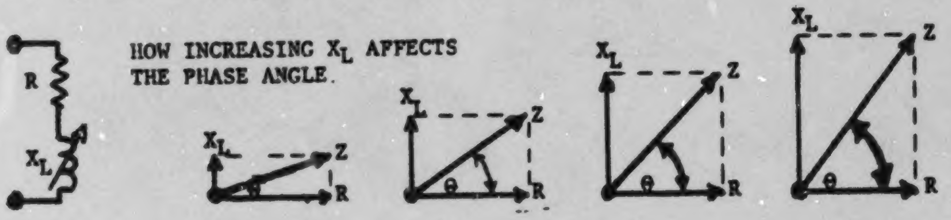
A-31 a. True....often vector diagrams are used to explain how a circuit functions electrically.

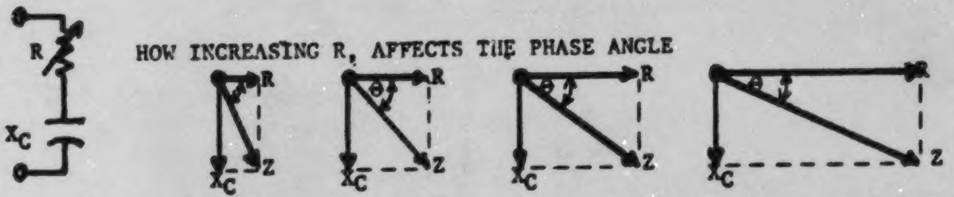
b. True and False and Sometimes.....it all depends upon how familiar vectors and equations are. It's an individual choice!

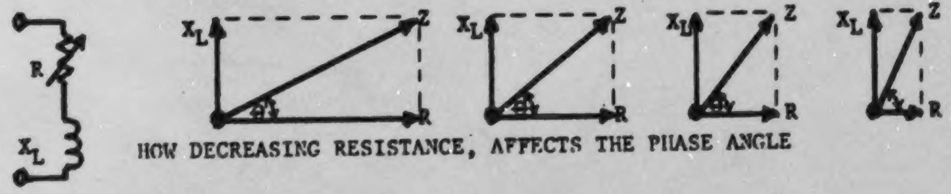
NOTE: Finally....."that" angle. Is it realy the Phase Angle θ ?

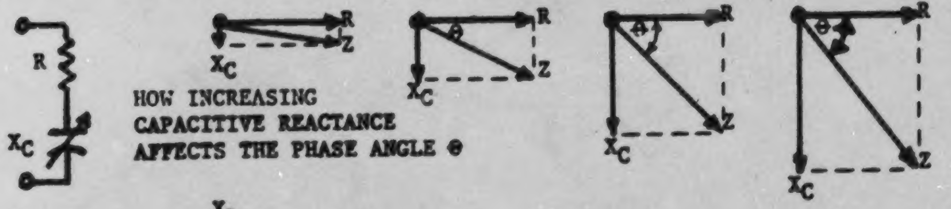
USING IMPEDANCE VECTORS (cont)

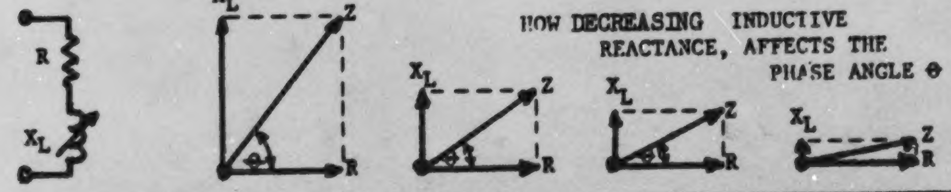
Notice how the circuit PHASE ANGLE (θ) increases or decreases, when Resistance (R), or Reactance (X_C and X_L) changes.


HOW INCREASING X_L AFFECTS THE PHASE ANGLE.


HOW INCREASING R, AFFECTS THE PHASE ANGLE


HOW DECREASING RESISTANCE, AFFECTS THE PHASE ANGLE


HOW INCREASING CAPACITIVE REACTANCE AFFECTS THE PHASE ANGLE θ


HOW DECREASING INDUCTIVE REACTANCE, AFFECTS THE PHASE ANGLE θ

Q-33 a. In an RL circuit, what will happen to (θ), if frequency inc?____

b. In an RL circuit, what will happen to (θ), if R increases?____

c. In an RL circuit, what will happen to (θ), if L decreases?____

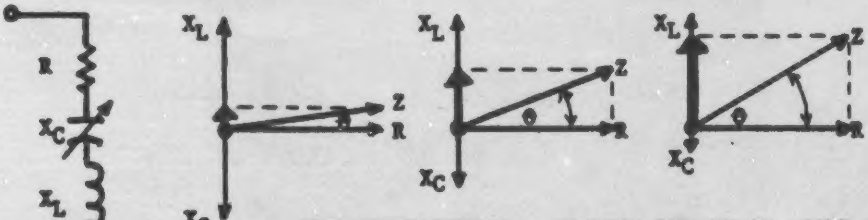
d. In an RC circuit, what will happen to (θ), if C increases?____

e. In an RC circuit, what will happen to (θ), if frequency inc?____

A-32 a. True....the more accurate the drawing, the more accurate will be the Impedance measurement.
b. True....although it is NOT the Phase Angle, it has the same number of degrees, and is often marked as (θ).
c. True....see answer (b) above.

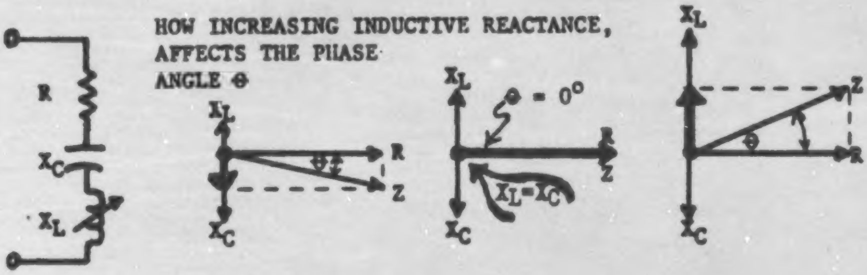
USING IMPEDANCE VECTORS (cont)

RCL circuits, containing all three vectors (R, X_C, and X_L), are somewhat more difficult. Observe the shift in the PHASE ANGLE (θ) when the following changes are made.

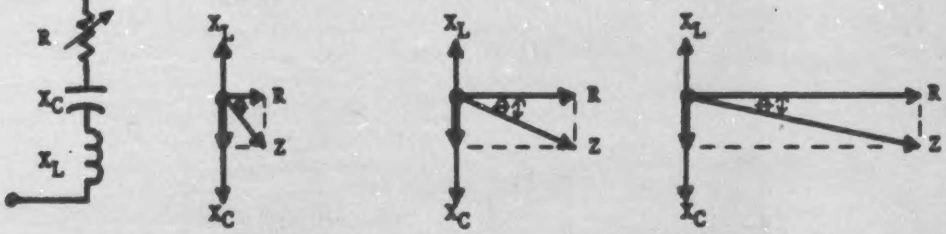


HOW DECREASING X_C, CHANGES THE PHASE ANGLE θ

HOW INCREASING INDUCTIVE REACTANCE, AFFECTS THE PHASE ANGLE θ



HOW INCREASING RESISTANCE AFFECTS THE PHASE ANGLE θ



Q-34 a. In an RCL Circuit, operating inductively, what will happen to (θ) if the frequency is increased?_______
b. In an RCL Circuit, operating inductively, what will happen to (θ) if the Resistance (R) is decreased?_______
c. In an RCL Circuit, operating inductively, what will happen to (θ) if the Inductance (L) is increased?________
d. In an RCL Circuit, operating CAPACITIVELY, what will happen to (θ) if the frequency is increased?_______
e. In an RCL Circuit, operating capacitively, what will happen to (θ) if the Resistance (R) is decreased?________

A-33 a. Inc....inc freq = inc X_L = inc (Θ).
b. Dec....inc R = dec (Θ).
c. Dec....dec L (Inductance) = dec X_L = dec (Θ).
d. Dec....inc C (Capacitance) = dec X_C = dec (Θ).
e. Dec....inc frequency = dec X_C = dec (Θ)

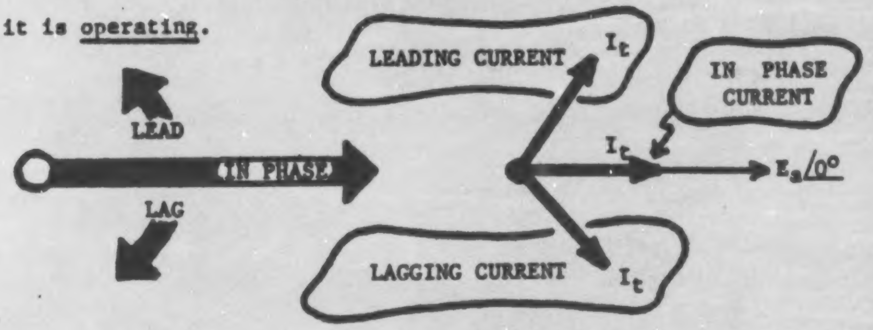
$X_L = 2\pi fL$

$X_C = \frac{1}{2\pi fC}$

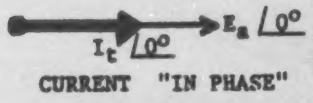
VOLTAGE AND CURRENT VECTORS

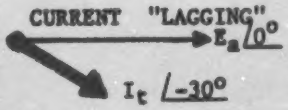
The angular difference between the Applied Voltage (E_a), and the Total Current (I_t), is also represented as a vector diagram. The Applied Voltage (E_a) is drawn on the horizontal, similiar to the Resistance (R) vector. $\bullet\!\longrightarrow E_a$ It is also assigned a value of zero degrees. $\bullet\!\longrightarrow E_a\angle 0^\circ$

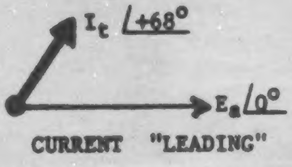
The Total Current (I_t) will "lead", "lag", or be "in phase with" the Applied Voltage (E_a). It depends upon the type of circuit, and how it is operating.


LEADING CURRENT
I_t
IN PHASE CURRENT
LEAD
IN PHASE
I_t
$E_a\angle 0^\circ$
LAG
LAGGING CURRENT
I_t

Positive angles are assigned to "leading" currents. "Lagging" currents are marked as negative angles. "In phase" currents are indicated as zero degrees.


$E_a\angle 0^\circ$
$I_t\angle 0^\circ$
CURRENT "IN PHASE"


CURRENT "LAGGING"
$E_a\angle 0^\circ$
$I_t\angle -30^\circ$


$I_t\angle +68^\circ$
$E_a\angle 0^\circ$
CURRENT "LEADING"

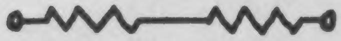
Q-35 a. The angular difference between the Applied Voltage (E_a) and the Total Current (I_t), is called the ________ Angle (Θ).
b. The Total Current (I_t), will "lead", "lag", or be "___ ___ ___" the Applied Voltage (E_a).
c. T-F, Positive angles are assigned to "leading" currents.
d. T-F, Positive angles are assigned to "lagging" currents.
e. T-F, A current angle marked $\angle -45^\circ$ would be "leading" (E_a).
f. T-F, A current angle marked $\angle +22^\circ$ would be "leading" (E_a).

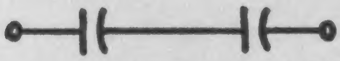
A-34 a. Inc.....freq inc = X_L inc = θ inc
b. Inc.....dec R = inc θ....(look carefully)
c. Inc.....inc L = inc X_L = inc θ $\quad X_L = 2\pi fL$
d. Dec.....inc freq = dec X_C = dec θ
e. Inc.....dec R = inc θ....(check carefully) $\quad X_C = \frac{1}{2\pi fC}$

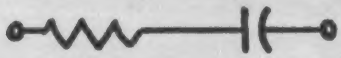
VOLTAGE AND CURRENT VECTORS (cont)

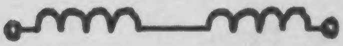
The Total Current (I_t) will "lead", "lag", or be "in phase with" the Applied Voltage (E_a). It depends upon the type of circuit, and how it is operating. Reviewing the "operating characteristics"....

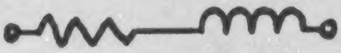
This CIRCUIT.................. is OPERATING....


Purely resistive or resistively


Purely capacitive

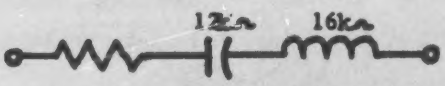

Capacitively


Purely inductive

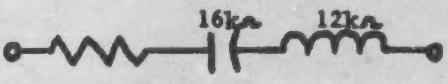

Inductively

In the case of Series RCL Circuits, the opposition of the capacitor and inductor determine how the circuit will operate.

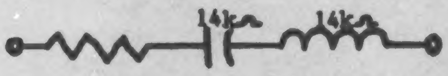
This CIRCUIT...................is OPERATING....



Inductively (X_L larger)



Capacitively (X_C larger)



Resistively (X_L & X_C equal)

Q-36 a. The factor which determines whether the current will be "leading" "lagging" or "in phase" with the voltage, is how the circuit is ________________.
b. RC circuits, "operate" ________________.
c. RL circuits, "operate" ________________.
d. RCL circuits, (with X_C and X_L equal), "operate" ____________.

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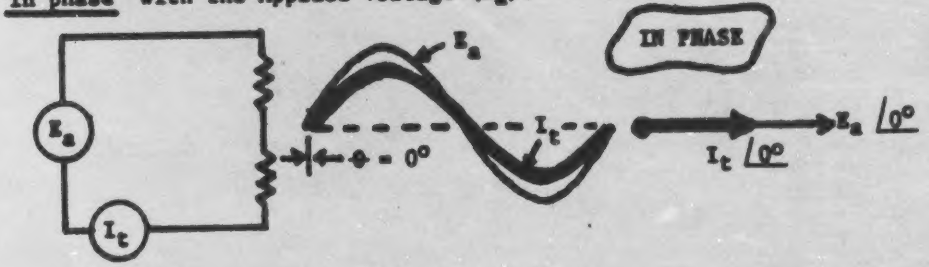
A-35 a. Phase Angle (Θ)
b. "in phase with"
c. True
d. False...."lagging" currents have negative angles assigned.
e. False....it would be "lagging" by 45 degrees.
f. True

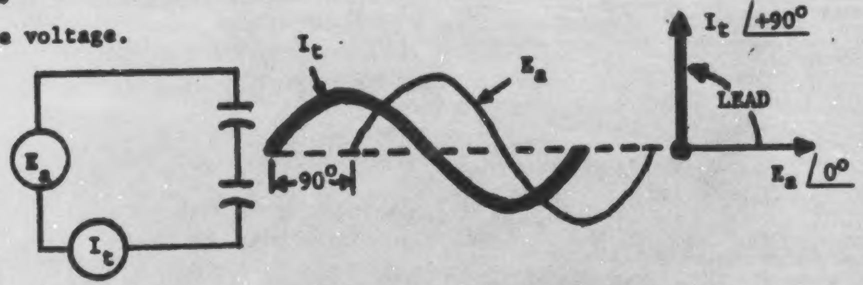
VOLTAGE AND CURRENT VECTORS (cont)

In "purely resistive" circuits, the Total Current (I_t) will be "in phase" with the Applied Voltage (E_a).



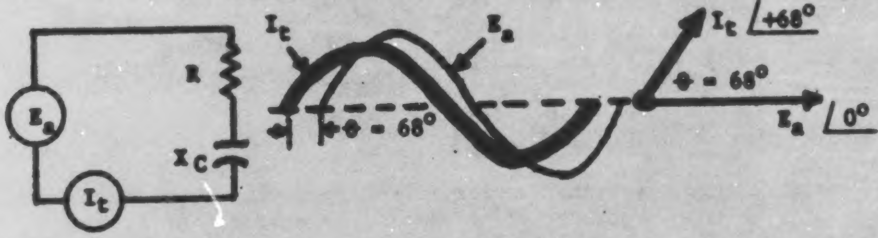
E_a
IN PHASE
E_a
I_t
Θ = 0°
$E_a \angle 0°$
$I_t \angle 0°$
I_t

In "purely capacitive" circuits, the Total Current (I_t), will be 90° out of phase with the Applied Voltage (E_a). The current will LEAD the voltage.



$I_t \angle +90°$
I_t
E_a
LEAD
E_a
90°
$E_a \angle 0°$
I_t

In a Series RC circuit, operating "capacitively", the Total Current (I_t) will LEAD the Applied Voltage (E_a), but NOT by the full 90°. It will lead by the PHASE ANGLE (Θ), for that particular circuit.



I_t
E_a
$I_t \angle +68°$
R
Θ = 68°
E_a
Θ = 68°
$E_a \angle 0°$
X_C
I_t

Remember! The Resistance (R), and the Capacitive Reactance (X_C), determine the exact number of degrees in the PHASE ANGLE (Θ).

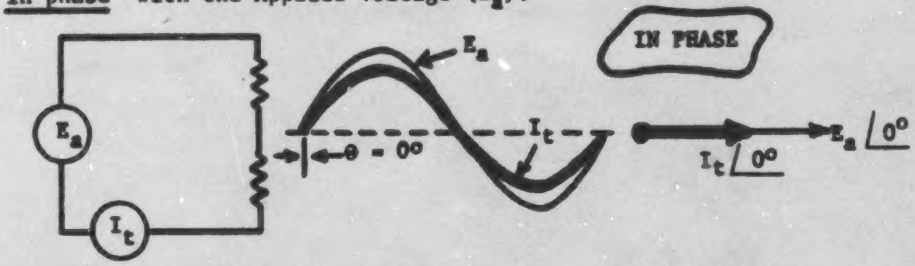
Q-37 a. In "capacitive" circuits, current __________ voltage.
b. T-F In an RC circuit, I_t "leads" E_a by 90 degrees.

A-36
a. operating or acting

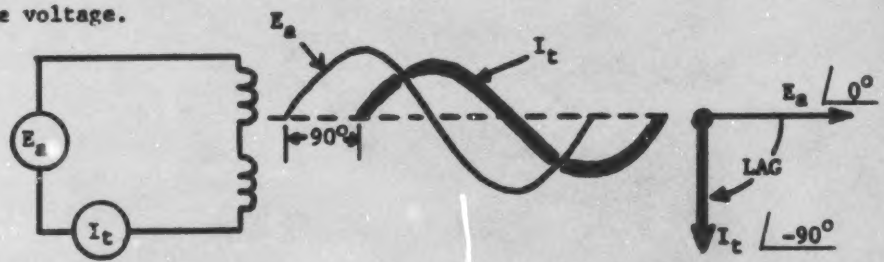
b. capacitively
c. inductively
d. resistively (with X_C and X_L equal)

VOLTAGE AND CURRENT VECTORS (cont)

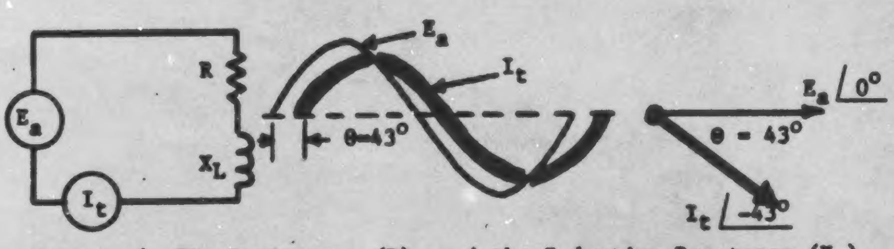
In "purely resistive" circuits, the Total Current (I_t) will be "in phase" with the Applied Voltage (E_a).


IN PHASE
E_a
E_a
I_t
I_t
$\theta = 0°$
$E_a \angle 0°$
$I_t \angle 0°$

In "purely inductive" circuits, the Total Current (I_t), will be 90° out of phase with the Applied Voltage (E_a). The current will LAG the voltage.


E_a
I_t
E_a
I_t
90°
$E_a \angle 0°$
LAG
$I_t \angle -90°$

In a Series RL circuit, operating "inductively", the Total Current (I_t) will LAG the Applied Voltage (E_a), but NOT by the full 90°. It will lag by the PHASE ANGLE (θ), for that particular circuit.


E_a
I_t
R
X_L
E_a
I_t
$\theta = 43°$
$E_a \angle 0°$
$\theta = 43°$
$I_t \angle -43°$

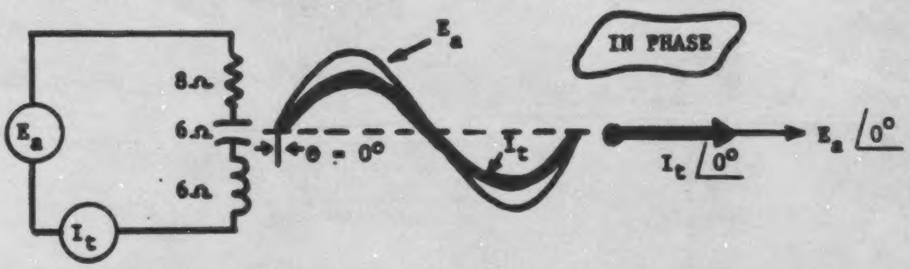
Remember! The Resistance (R), and the Inductive Reactance (X_L), determine the exact number of degrees in the PHASE ANGLE (θ).

Q-38 a. In an "inductive" circuit, current ___________ voltage.
b. In an RL circuit, I_t "lags" E_a by 90 degrees. (T-F)

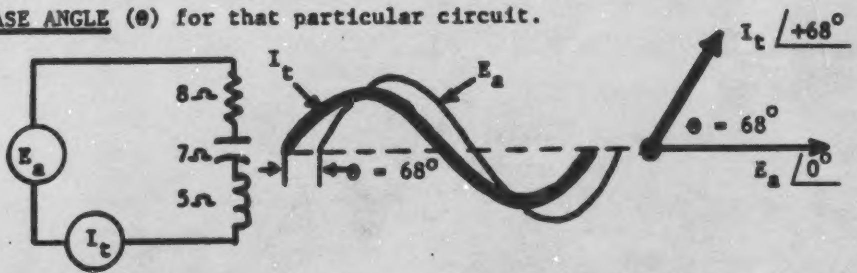
A-37 a. "leads"
b. False....current leads voltage by the "phase angle"

VOLTAGE AND CURRENT VECTORS

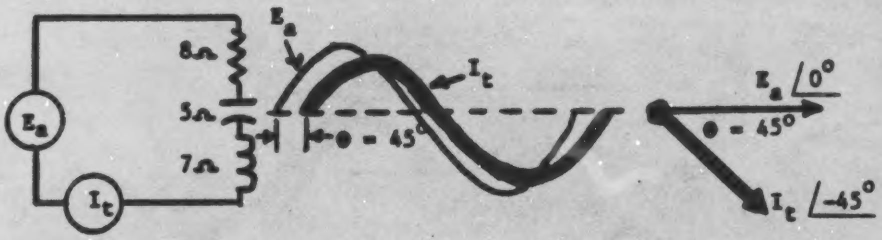
In Series RCL Circuits operating "resistively", the Total Current (I_t), will be "in phase" with the Applied Voltage (E_a).


E_a
IN PHASE
8Ω
6Ω
6Ω
E_a
I_t
$\theta = 0^\circ$
I_t
$E_a \angle 0^\circ$
$I_t \angle 0^\circ$

In Series RCL Circuits operating "capacitively", the Total Current (I_t), will LEAD the Applied Voltage (E_a). It will LEAD by the PHASE ANGLE (θ) for that particular circuit.


$I_t \angle +68^\circ$
I_t
E_a
8Ω
7Ω
5Ω
E_a
I_t
$\theta = 68^\circ$
$\theta = 68^\circ$
$E_a \angle 0^\circ$

In Series RCL Circuits operating "inductively", the Total Current (I_t), will LAG the Applied Voltage (E_a). It will LAG by the PHASE ANGLE (θ) for that particular circuit.


E_a
I_t
8Ω
5Ω
7Ω
E_a
I_t
$\theta = 45^\circ$
$E_a \angle 0^\circ$
$\theta = 45^\circ$
$I_t \angle -45^\circ$

The factors that determine the exact PHASE ANGLE (θ) for these circuits are: Resistance (R), Capacitive Reactance (X_C) and Inductive Reactance (X_L).

Q-39 a. T-F In a "capacitive" RCL circuit, current "leads" voltage.
b. T-F In an "inductive" RCL circuit, current "leads" voltage.

A-38 a. "lags"
b. False....in an RL circuit, the total current will "lag" the applied voltage by whatever the Phase Angle (θ) for that particular circuit is.

VOLTAGE AND CURRENT VECTORS (cont)

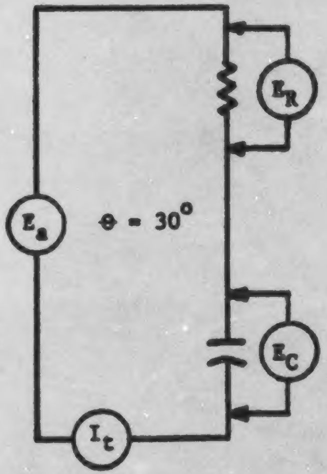
The "voltage drops" which occur in Series Reactive Circuits, are also represented by vectors. Three RULES determine the positions of these voltage vectors.

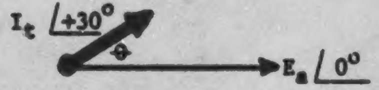
1 E_R The voltage drop will always be IN PHASE with the current.

2 E_C The voltage drop will always LAG the current by 90 degrees.

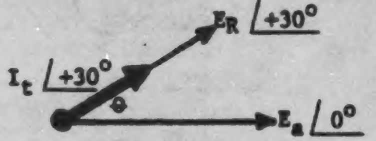
3 E_L The voltage drop will always LEAD the current by 90 degrees.

In a Series RC Circuit, the Applied Voltage (E_a), and the Total Current (I_t) vectors are drawn first. They should be drawn, the PHASE ANGLE (θ) apart, for that particular circuit.

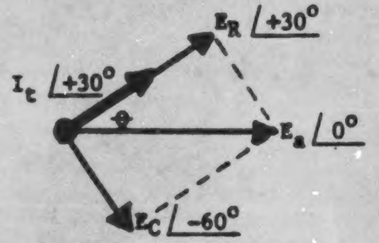

E_R
E_a
θ = 30°
E_C
I_t


$I_t \angle +30°$
θ
$E_a \angle 0°$

Following RULE 1, the Resistor Voltage (E_R) is then drawn IN PHASE with the current.


$E_R \angle +30°$
$I_t \angle +30°$
θ
$E_a \angle 0°$

Following RULE 2, the Capacitor Voltage (E_C) is then drawn 90 degrees LAGGING the current.


$E_R \angle +30°$
$I_t \angle +30°$
θ
$E_a \angle 0°$
$E_C \angle -60°$

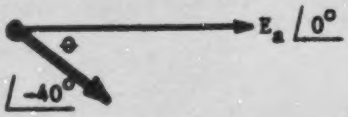
This is the completed VOLTAGE AND CURRENT vector diagram for Series RC Reactive Circuits.

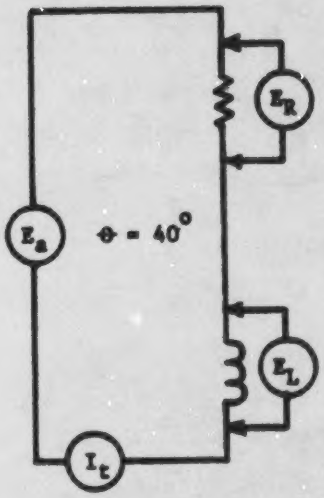
Q-40 a. E_R is always "in phase" with the ____________.
b. E_C always "lags" current by 90 degrees. (T-F)

A-39
a. True
b. False....in "inductive" circuits, current "lags" voltage,

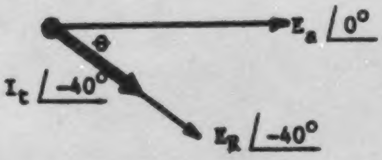
VOLTAGE AND CURRENT VECTORS (cont)

In a Series RL Circuit, the Applied Voltage (E_a), and the Total Current (I_t) vectors are drawn first. They should be drawn, the PHASE ANGLE (θ) apart, for that particular circuit.

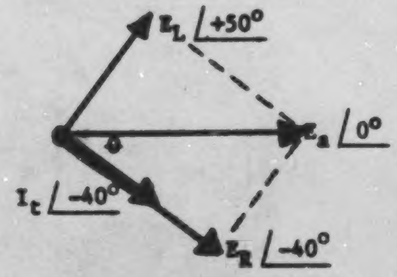

$E_a \angle 0^\circ$
θ
$I_t \angle -40^\circ$


E_R
E_a
θ = 40°
E_L
I_t

Following RULE 1, the Resistor Voltage (E_R) is then drawn IN PHASE with the current.

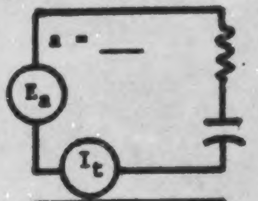

$E_a \angle 0^\circ$
θ
$I_t \angle -40^\circ$
$E_R \angle -40^\circ$

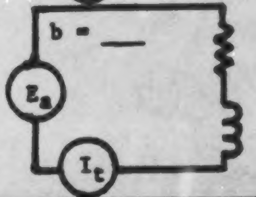
Following RULE 3, the Inductor Voltage (E_L) is then drawn LEADING the current by 90°.

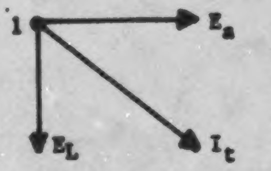

$E_L \angle +50^\circ$
$E_a \angle 0^\circ$
θ
$I_t \angle -40^\circ$
$E_R \angle -40^\circ$

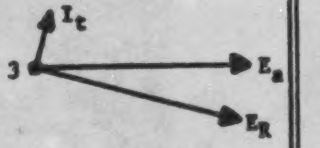
This is the completed VOLTAGE AND CURRENT vector diagram for Series RL Reactive Circuits.

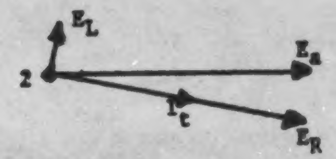
Q-41 Match the circuits with their proper VOLTAGE-CURRENT diagram.

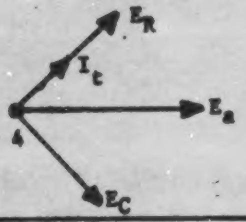










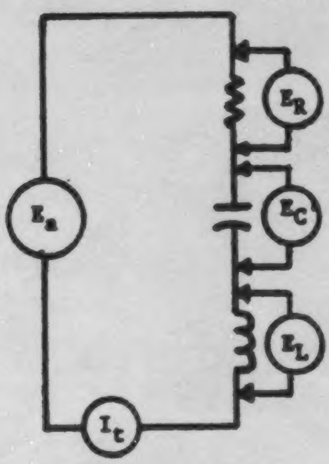


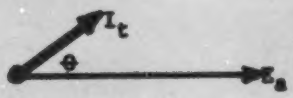
233

A-40 a. current.....ALWAYS "in phase" with the current!
b. True........ALWAYS "lags" by 90 degrees!

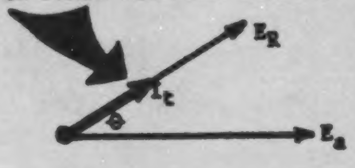
VOLTAGE AND CURRENT VECTORS (cont)

Concerning Series RCL Circuits, the first example will be for one operating "capacitively", with its LEADING current.

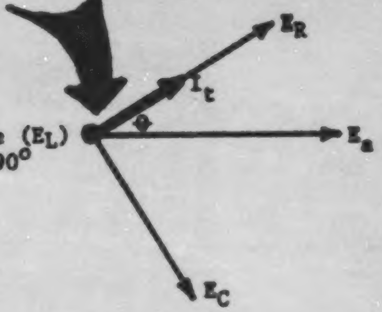




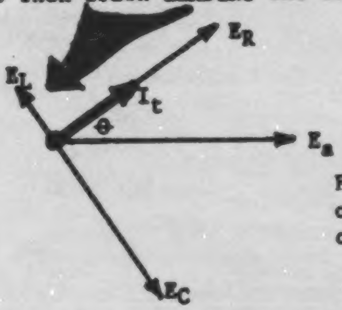
Following RULE 1, the Resistor Voltage (E_R) is then drawn IN PHASE with the current.



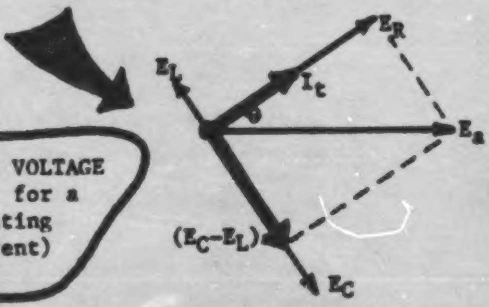
Following RULE 2, the Capacitor Voltage (E_C) is then drawn LAGGING the current by 90°.



Following RULE 3, the Inductor Voltage (E_L) is then drawn LEADING the current by 90°



Finally, as E_C and E_L are opposite (180° out of phase), a "difference" vector is created, and drawn in. (E_C - E_L)



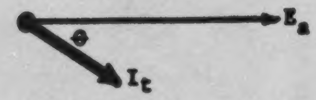
This is the completed VOLTAGE CURRENT vector diagram, for a Series RCL Circuit, operating CAPACITIVELY. (Leading current)

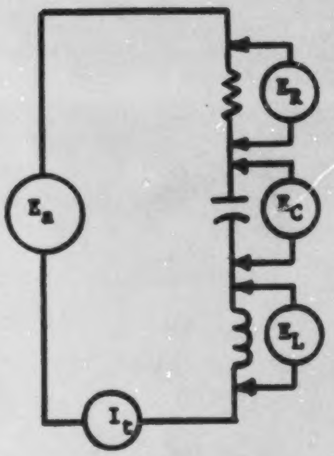
Q-42 a. T-F In any RCL circuit, E_R is "in phase" with the current.
b. T-F In a "capacitive" RCL circuit, I_t "lags" E_a.
c. T-F In a "capacitive" RCL circuit, E_L "leads" E_a.
d. T-F In a "capacitive" RCL circuit, E_C "lags" E_a by 90 degrees.
e. T-F In a "capacitive" RCL circuit, E_C "leads" E_R by 90°.

A-41	a = 4	b = 2

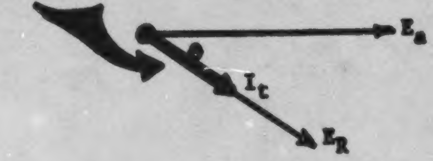
VOLTAGE AND CURRENT VECTORS (cont)

The VOLTAGE-CURRENT vector diagram for an RCL Circuit, operating "inductively", is developed as follows. INDUCTIVE (Lagging current)

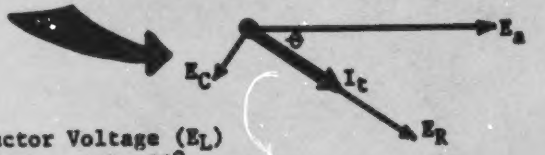




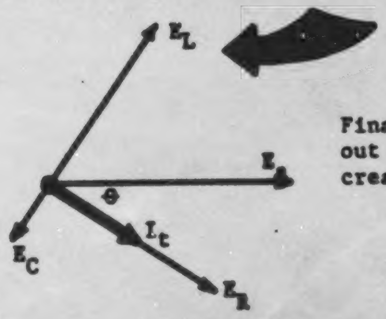
Following RULE 1, the Resistor Voltage (E_R) is then drawn IN PHASE with the current.



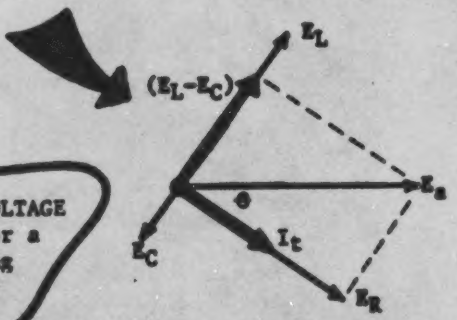
Following RULE 2, the Capacitor Voltage (E_C) is then drawn LAGGING the current by 90°.



Following RULE 3, the Inductor Voltage (E_L) is then drawn LEADING the current by 90°.



Finally, as E_L and E_C are opposite (180° out of phase), a "difference" vector is created, and drawn in. (E_L - E_C)



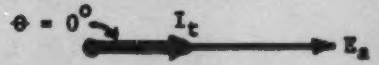
This is the completed VOLTAGE CURRENT vector diagram, for a Series RCL Circuit, operating INDUCTIVELY. (Lagging current)

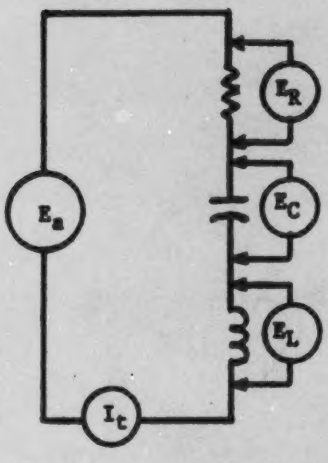
Q-43 a. T-F. In any "inductive" circuit, current "lags" voltage.
b. T-F. In an "inductive" RCL circuit, E_R "lags" E_a.
c. T-F. In an "inductive" RCL circuit, E_L "leads" E_a.
d. T-F. In an "inductive" RCL circuit, E_C "leads" E_a.
e. T-F. In an "inductive" RCL circuit, E_L "leads" E_r by (θ).

A-42 a. True.....E_R is ALWAYS "in phase" with the current.
b. False....the current "leads" E_a by the Phase Angle (θ).
c. True.....by the Phase Angle (θ) + 90 degrees.
d. False....it "lags" OK....but NOT by 90 degrees.
e. False....E_C "lags" E_R by 90 degrees.

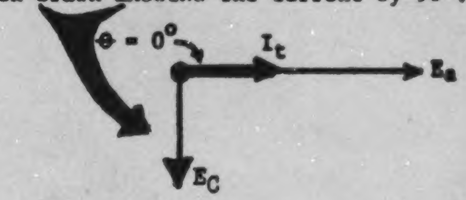
VOLTAGE AND CURRENT VECTORS (cont)

The VOLTAGE-CURRENT vector diagram for an RCL Circuit, operating "resistively", is developed as follows. RESISTIVE (In-phase current)

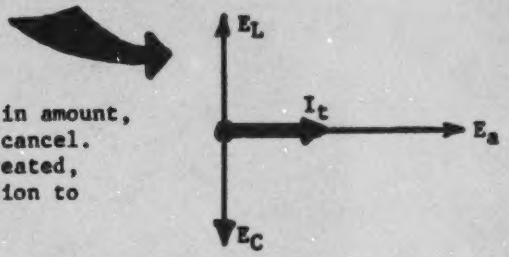




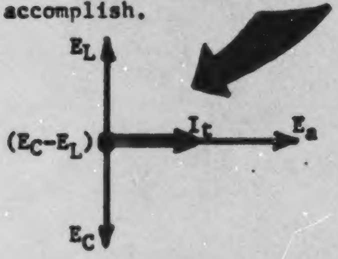
Following RULE 2, the Capacitor Voltage (E_C) is then drawn LAGGING the current by 90°.



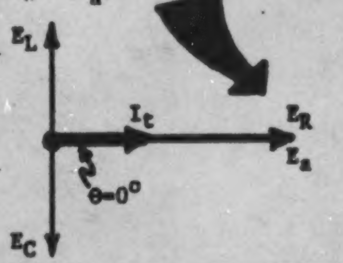
Following RULE 3, the Inductor Voltage (E_L) is then drawn LEADING the current by 90°.



Because E_C and E_L are equal in amount, and opposite in phase, they cancel. NO "difference" vector is created, and there is NO vector addition to accomplish.



Since E_C and E_L cancelled each other, only the Resistor Voltage (E_R) remains. Following RULE 1, the Resistor Voltage (E_R) is then drawn IN PHASE with the current, and equal to the Applied Voltage (E_a).



This is the completed VOLTAGE CURRENT vector diagram, for a Series RCL Circuit, operating RESISTIVELY. (In-phase current)

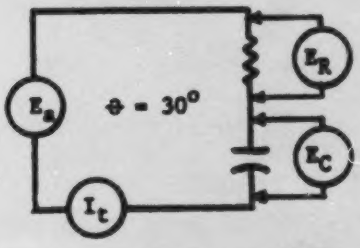
Q-44 a. The Total Current (I_t) is "in phase" with the Applied Voltage (E_a), in RCL circuits "operating" ________________.
b. T-F In RCL circuits E_C "leads" and E_L "lags" the current.

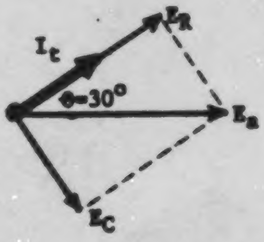
A-43 a. True
b. True......by the Phase Angle (θ).
c. True......by 90 degrees minus the Phase Angle (θ).
d. False.....it "lags" E_a by the Phase Angle (θ) + 90 degrees.
e. False.....it "leads" OK, but not by the Phase Angle (θ).

USING VOLTAGE VECTORS

Later, in Electronics training, voltage vectors will be used to explain the operation of many complex circuits. At this time, they will be used to show the expected results, when these voltages are displayed on an Oscilloscope.

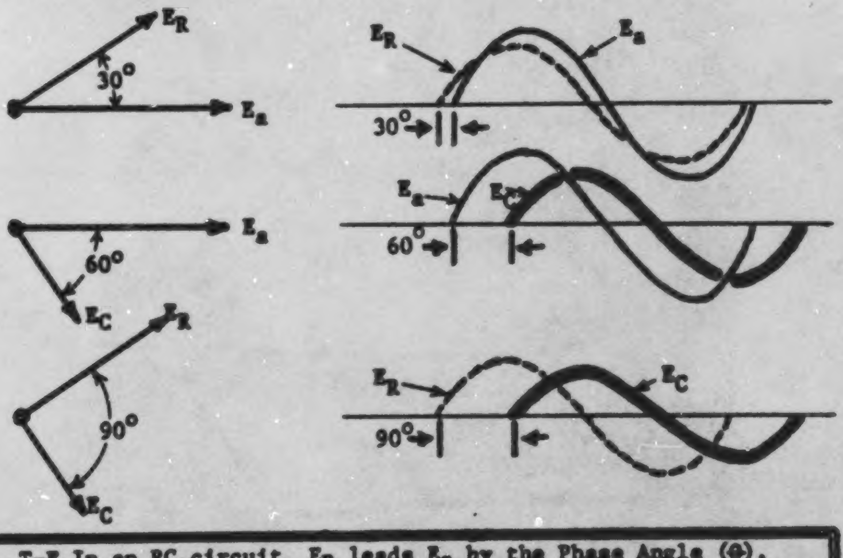
For example: If the PHASE ANGLE (θ), for a Series RC Circuit, is 30 degrees, the voltage-current vector is as follows.





The following Oscilloscope displays would be observed.

USING THESE TWO VOLTAGES..........THIS DISPLAY WILL BE SEEN

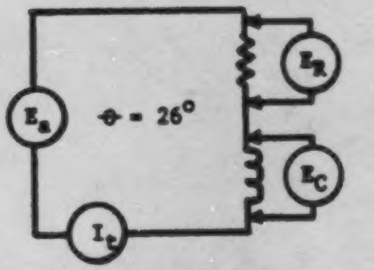


Q-45 a. T-F In an RC circuit, E_R leads E_a by the Phase Angle (θ).
b. T-F In an RC circuit, E_C and E_R are 90 degrees out of phase.
c. T-F In an RC circuit, E_C and E_a are 90 degrees out of phase.

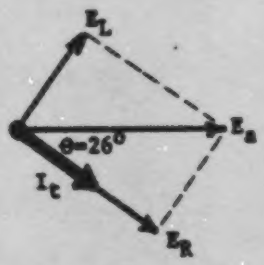
A-44
a. resistively
b. False.....just the reverse.....in all RCL circuits, E_L "leads" current, and E_C "lags" current.

USING VOLTAGE VECTORS (cont)

If the PHASE ANGLE (θ), for a Series RL Circuit, is 26 degrees, the voltage-current vector diagram is as follows:



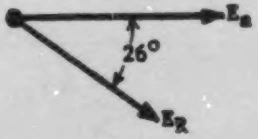
E_a
θ = 26°
E_R
E_C
I_t

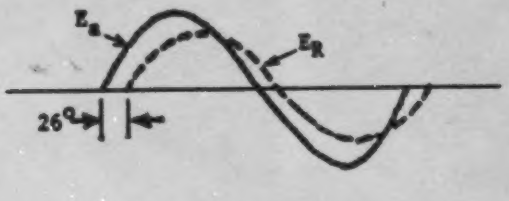


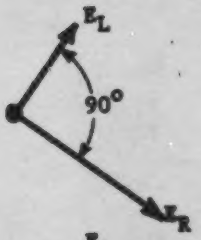
E_L
E_a
θ=26°
I_t
E_R

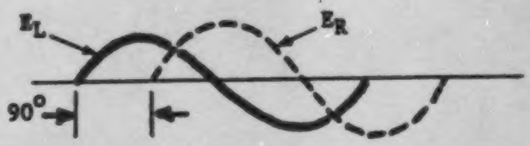
The following Oscilloscope displays would be observed.

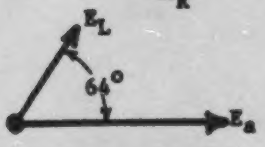
USING THESE TWO VOLTAGES.........THIS DISPLAY WILL BE SEEN

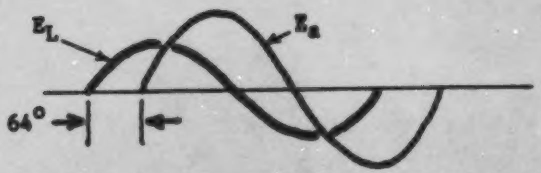










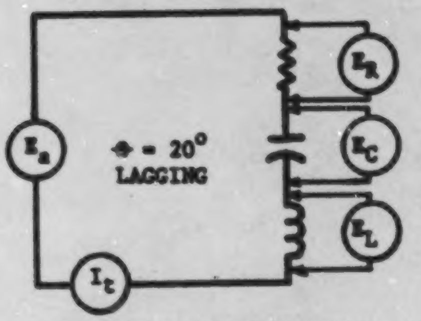


Q-46
a. T-F In an RL circuit, E_R and E_a are (θ), out of phase.
b. T-F In an RL circuit, E_L and E_a are (θ), out of phase.
c. T-F In an RL circuit, E_L "lags" E_R by 90 degrees.
d. T-F In an RL circuit, E_a "lags" E_L.

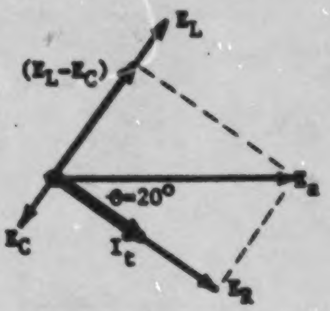
A-45
- a. True
- b. True
- c. False....they are 90 degrees minus (Θ), out of phase.

USING VOLTAGE VECTORS (cont)

An RCL Circuit, with a PHASE ANGLE (Θ) of 20 degrees INDUCTIVE.

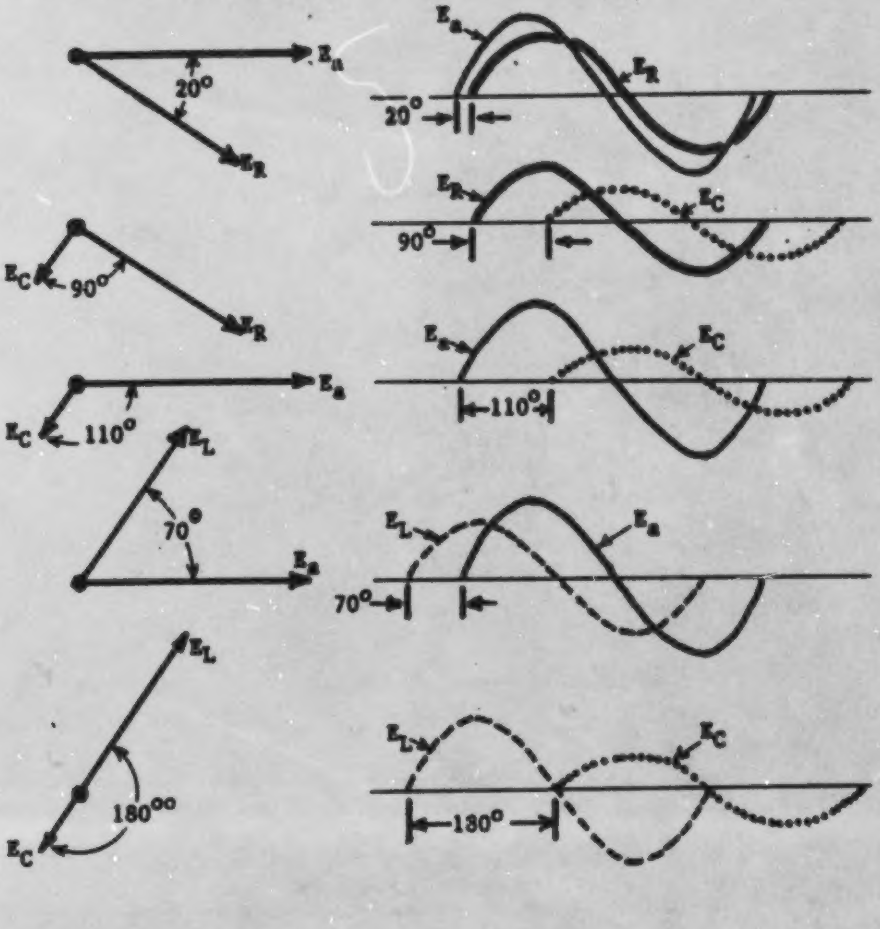


E_a
Θ = 20°
LAGGING
E_R
E_C
E_L
I_t



E_L
(E_L-E_C)
E_a
Θ=20°
E_C
I_t
E_R

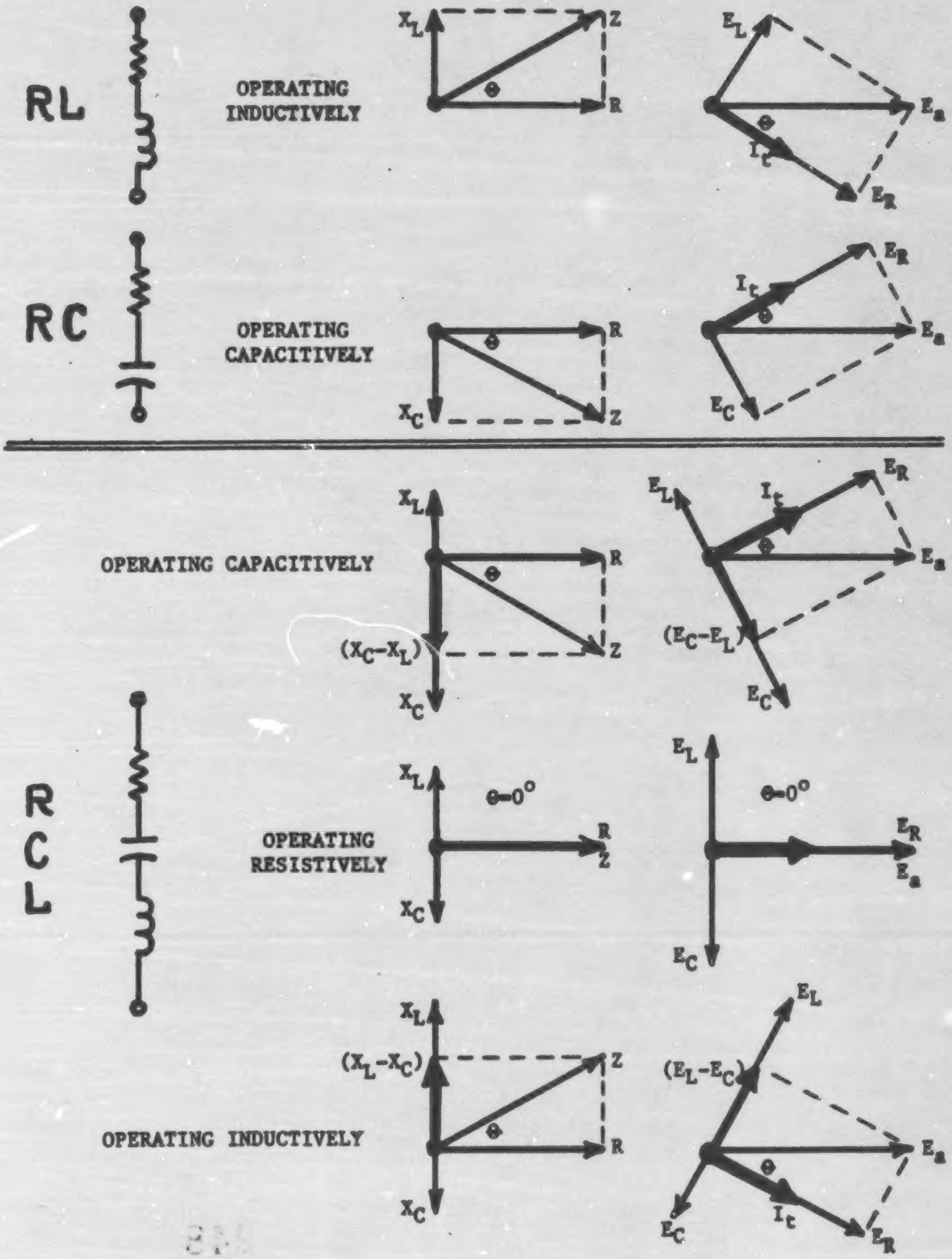
USING THESE TWO VOLTAGES..........THIS DISPLAY WILL BE SEEN



E_a
20°
E_R
E_a
E_R
20°
E_R
E_C
90°
E_R
E_C
90°
E_a
E_C
110°
E_a
E_C
110°
E_L
70°
E_a
E_L
E_a
70°
E_L
180°°
E_C
E_L
E_C
130°

A-46
a. True....with E_R lagging E_a
b. False...they are 90 degrees minus the Phase Angle, out of phase.
c. False...E_L leads E_R by 90 degrees.
d. True....they are 90° minus (θ), out of phase.

VECTOR SUMMARY **IMPEDANCE VECTOR** **VOLTAGE-CURRENT VECTOR**


RL
OPERATING INDUCTIVELY
X_L
Z
θ
R
E_L
E_a
θ
I_t
E_R
RC
OPERATING CAPACITIVELY
R
θ
X_C
Z
E_R
I_t
θ
E_a
E_C
OPERATING CAPACITIVELY
X_L
R
θ
(X_C-X_L)
Z
X_C
E_L
I_t
E_R
θ
E_a
(E_C-E_L)
E_C
R
C
L
OPERATING RESISTIVELY
X_L
θ=0°
R
Z
X_C
E_L
θ=0°
E_R
E_a
E_C
OPERATING INDUCTIVELY
X_L
(X_L-X_C)
Z
θ
R
X_C
E_L
(E_L-E_C)
E_a
θ
E_C
I_t
E_R

SUMMARY

This study of Reactive Circuits is only a beginning, providing the basic theory and calculations involved. Using this thorough "start", more advanced circuit theory can now be studied and understood. Technical reference centers provide many publications on the use and applications of "reactive" circuits.

Many of these publications have vector diagrams for detailed explanation, and using the knowledge gained here, a more complete understanding can be obtained.

The use of Trigonometry in the solution of reactive circuits, is an accepted practice in most technical books, and the skills now learned should be put to use, studying advanced circuitry.

It has not been an "easy" subject. It was never intended to be. Combinations of resistors, capacitors, and inductors, form the controlling centers of all radio, television, radar, communications, and Space systems. The maintenance of this critical equipment, can only be accomplished by qualified technicians, who understand that it is the "inter-working" of simple components which results in the high standards of equipment performance required today.

Reactive Circuits.....in the middle of it ALL!

PREPARE THE MAN

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-22

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

Module 22

PARALLEL RCL CIRCUITS

1 July 1974

7-7

Keesler Technical Training Center
Keesler Air Force Base, Mississippi

Supersedes KEP-GP-22, 1 November 1973, which will be used until stock is exhausted.

Designed For ATC Course Use

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Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-22
1 July 1974

Electronic Principles

PARALLEL RCL CIRCUITS

Module 22

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

TITLE	PAGE
Overview	1
List of Resources	2
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Adjunct Guide	6
Module Self-Check	13

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PARALLEL RCL CIRCUITS

1. SCOPE: This module expands on your knowledge of capacitors, coils, and resistors as they apply to RCL circuits. You will compute voltage drop, currents, phase angle, impedance, and power factor for parallel RCL circuits.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives.

a. Given a parallel RCL circuit diagram with component values, applied voltage, frequency, and formulas, solve for power factor, true power, and apparent power.

b. Given a parallel RCL circuit and vector diagrams, select the vector diagram representing the relative amplitude and phase relationships of I_t, I_R, I_C, and I_L.

c. Given a parallel RCL circuit diagram with component values, frequency, amplitude of applied voltage, and formulas, solve for branch currents, approximate phase angle, total current, and total impedance.

d. Given a parallel RCL circuit diagram with component values, branch currents, and formulas, solve for applied voltage.

e. Given a parallel RCL circuit diagram with component values and formulas, solve for total impedance by assuming an applied voltage.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK.

IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

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LIST OF RESOURCES

PARALLEL RCL CIRCUITS

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS

Digest

Adjunct Guide with Student Text

AUDIO-VISUALS

Television Lesson, Parallel RCL Circuits, TVK 30-263

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

PARALLEL RCL CIRCUITS

Let us review the properties of a basic parallel RCL circuit.

1. The voltage across each branch of a parallel circuit is the same.

2. Total current is the vector sum of the individual branch currents. Total current will be:

$$I_t = \sqrt{I_R^2 + (I_L - I_C)^2}$$

3. The current in each branch is given by Ohm's Law.

$$I_R = \frac{E_a}{R}$$

$$I_C = \frac{E_a}{X_C}$$

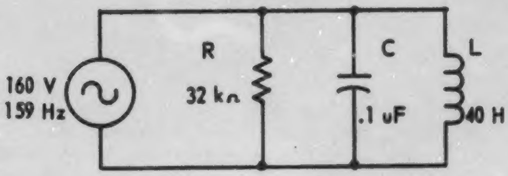
$$I_L = \frac{E_a}{X_L}$$

4. Due to the current and voltage relationships for a capacitor and inductor, the phase relationship of I_C and I_L are exactly opposite. Total reactive current will be the difference between the capacitive current and the inductive current.

A basic parallel RCL circuit is shown in figure 1. The first step in the solution of this parallel RCL problem is to determine X_C and X_L.

$$X_C = \frac{.159}{fC} = 10\ \text{k}\Omega$$

$$X_L = 2\pi fL = 40\ \text{k}\Omega$$



REP4-1079

Figure 1

Using Ohm's Law, solve for I_C (16 mA), I_L (4 mA), and I_R (5 mA).

$$I_t = \sqrt{I_R^2 + (I_C - I_L)^2} = 13\ \text{mA}$$

DIGEST

Using total current and the applied voltage, solve for total impedance.

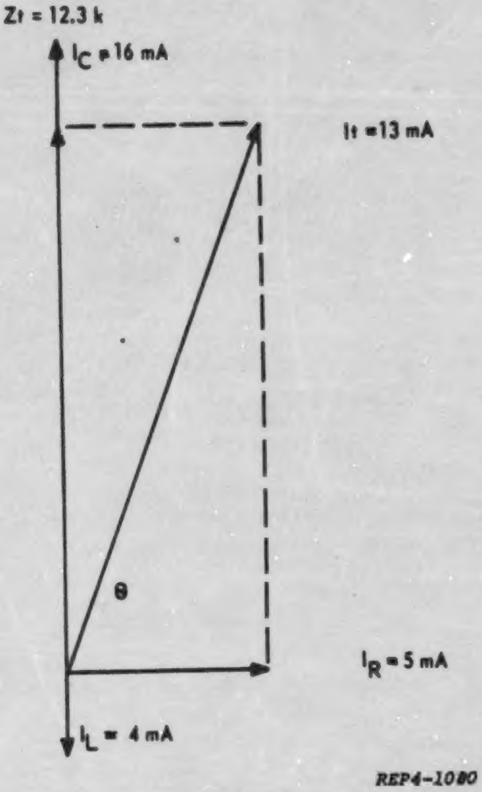


Figure 2

Figure 2 shows the relationship of the current values. Angle θ can be determined by using the cosine function.

$$\text{Cos } \theta = \frac{I_R}{I_t} = \frac{5 \text{ mA}}{13 \text{ mA}} = .3846$$

Referring to the trigonometric tables, find angle θ to be 67.4°.

We say the circuit is acting capacitively if the capacitive current is larger than the inductive current. How the circuit acts is determined by which reactive component has the larger current.

As with series RCL circuits, there is no real power dissipated by the capacitor or the inductor in a parallel RCL circuit. Real or true power (P_t) is the power dissipated by the resistor.

$$P_t = I_R E_R = \frac{E_R^2}{R} = I^2 R$$

The unit of measurement of P_t is the watt. Apparent power (P_a) is the product of E_a and I_t and is measured in volt amperes (VA).

$$P_t = I_R E_R = \frac{E_R^2}{R} = I^2 R$$

In this circuit, P is 2.08 V A and P_t is 800 mW. Power factor (PF) is the ratio of true power to apparent power.

$$PF = \frac{P_t}{P_a} = \frac{800 \text{ mW}}{2.08 \text{ VA}} = .3846$$

Notice that the PF is the same as the Cos of the phase angle (θ).

When the applied voltage is not given, you can solve for total impedance by using an assumed voltage. Use the assumed voltage and calculate the current through each branch. Combine the branch currents to determine total current. Use total current and the assumed voltage to calculate total impedance. Regardless what voltage is assumed, the impedance will be correct because impedance is the ratio of current to voltage.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

ADJUNCT GUIDE

PARALLEL RCL CIRCUITS

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

A. Turn to Student Text Volume III and read paragraphs 4-1 through 4-6. Return to this page and answer the following questions.

1. Mark true (T) or false (F) for each of the following statements pertaining to parallel circuits.

____ a. The voltage across all components is of exactly the same phase and amplitude.

____ b. The current is always the same through all branches.

____ c. The total current is the vector sum of the branch currents.

____ d. The voltage across a capacitor leads the current.

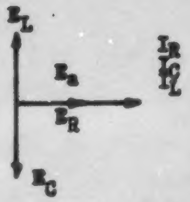
____ e. The current through a coil lags the voltage.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

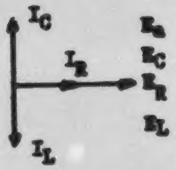
B. Turn to Student Text Volume III and read paragraphs 4-7 through 4-15. Return to this page and answer the following questions.

1. Identify the vector diagram for a parallel RCL circuit.

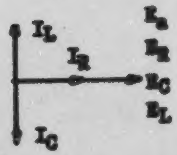
____ a.



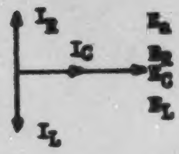
____b.


I_C
I_R
E_a
E_C
E_R
E_L
I_L

____c.


I_L
I_R
E_a
E_R
E_C
E_L
I_C

____d.


I_R
I_C
E_a
E_R
E_C
E_L
I_L

2. Solve for:

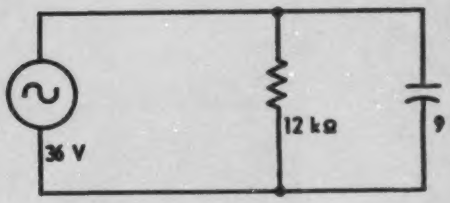
I_t = ________

Z = ________

I_R = ________

I_C = ________

θ = ________


36 V
12 kΩ
9 kΩ

REP4-1082

3. In this circuit find:

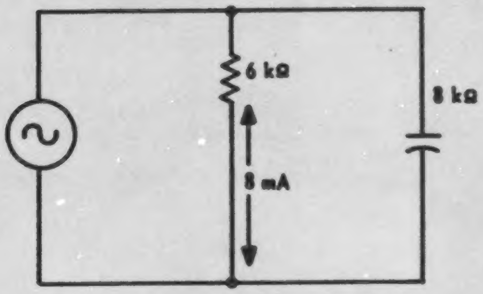
E_a = ________

I_C = ________

I_t = ________

Z = ________

θ = ________



REP4-1083

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

ANSWERS TO A:

1. a. T d. F

b. F e. T

c. T

If you missed any questions, review the material before you continue.

ANSWERS TO B:

1. b

2. I_t = 5 mA

Z = 7.2 kΩ

I_R = 3 mA

I_C = 4 mA

θ = 53.1°

3. E_a = 48 V

I_C = 6 mA

I_t = 10 mA

Z = 4.8 kΩ

θ = 36.9°

If you missed any questions review the material before you continue.

C. Turn to Student Text Volume III and read paragraphs 4-16 through 4-20. Return to this page and answer the following questions.

1. In the following circuit solve for:

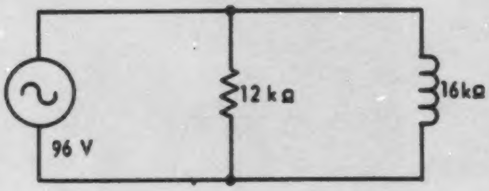
I_R = ________

I_L = ________

I_t = ________

Z = ________

θ = ________



REP4-1084

2. In this circuit solve for:

X_L = ______

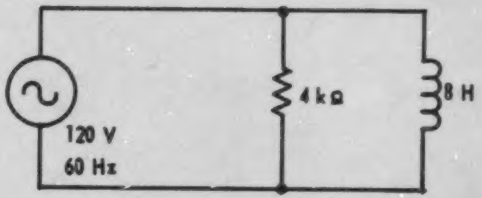
I_L = ______

I_R = ______

I_t = ______

Z = ______

θ = ______


120 V
60 Hz
4 kΩ
8 H

REP4-1085

3. Solve for:

I_R = ______

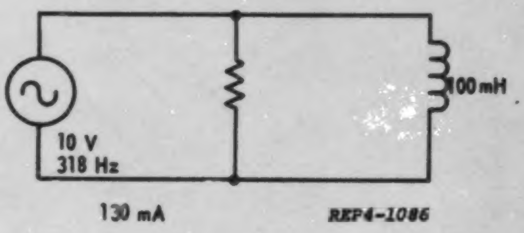
I_L = ______

X_L = ______

R = ______

Z = ______

θ = ______


10 V
318 Hz
100 mH
130 mA

REP4-1086

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

D. Turn to Student Text Volume III and read paragraphs 4-21 through 4-31. Return to this page and answer the following questions.

1. For the circuit shown, draw the current-voltage vectors and solve for:

I_R = ______

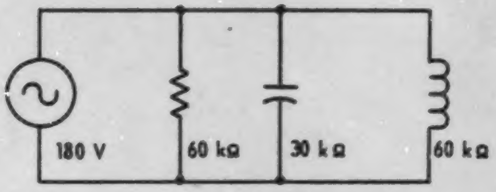
I_C = ______

I_L = ______

Z = ______

I_t = ______

θ = ______


180 V
60 kΩ
30 kΩ
60 kΩ

REP4-1087

ANSWERS TO C:

1. I_R = 8 mA

   I_L = 6 mA

   I_t = 10 mA

   Z = 9.6 kΩ

   θ = 36.9°

2. X_L = 3 kΩ

   I_L = 40 mA

   I_R = 30 mA

   I_t = 50 mA

   Z = 2.4 kΩ

   θ = 53.1°

3. I_R = 120 mA

   I_L = 50 mA

   X_L = 199.7Ω

   R = 83 Ω

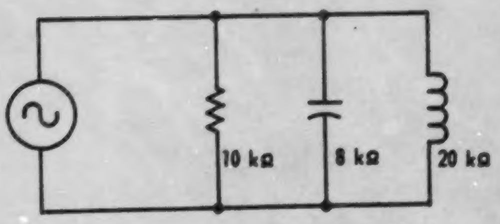
   Z = 76 Ω

   θ = 22.6°

If you missed any questions, review the material before you continue.

2. Solve for:

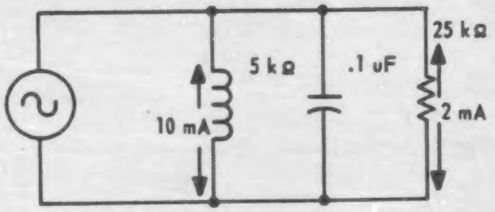
   Z = ________



REP4-1088

3. Solve for:

E_a = ________


25 kΩ
5 kΩ
.1 uF
10 mA
2 mA

REP4-1089

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

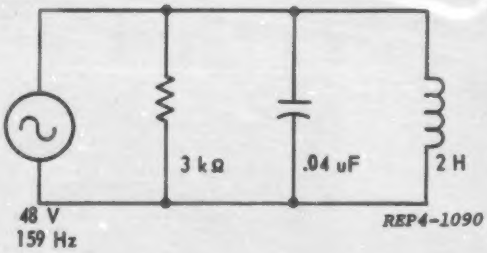
E. Turn to Student Text Volume III and read paragraphs 4-32 through 4-36. Return to this page and answer the following questions.

1. In this circuit find:

P_t = ________

P_a = ________

PF = ________


3 kΩ
.04 uF
2 H
48 V
159 Hz

REP4-1090

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

ANSWERS TO D:

1. $I_R = 3$ mA

   $I_C = 6$ mA

   $I_L = 3$ mA

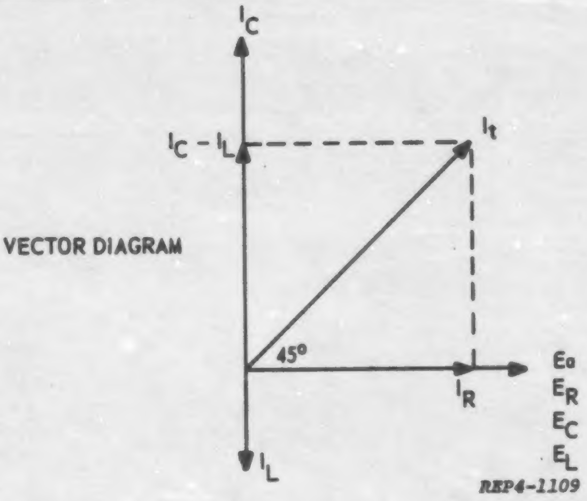
   $Z = 42.4\ \text{k}\ \Omega$

   $I_t = 4.24$ mA

   $\theta = 45°$

2. $Z = 8\ \text{k}\ \Omega$

3. $E_a = 50$ V


VECTOR DIAGRAM
I_C
$I_C - I_L$
I_t
45°
I_R
E_a
E_R
E_C
E_L
I_L
REP4-1109

If you missed ANY questions, review the material before you continue.

ANSWERS TO E:

1. $P_t = 768$ mW

   $P_a = 960$ mVA

   PF = .7997

If you missed ANY questions, review the material before you continue.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

PARALLEL RCL CIRCUITS

QUESTIONS:

1. Solve for:

I_R = ________

I_C = ________

I_t = ________

Z = ________

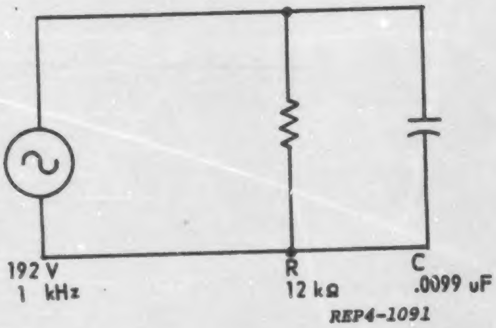
X_C = ________

P_t = ________

P_a = ________

PF = ________

θ = ________


192 V
1 kHz
R
12 kΩ
C
.0099 uF
REP4-1091

Draw the current vectors.

2. If the capacitor in problem one was replaced by a 1 pF unit, I_C would ____________________

and E_C would ______________________________.

3. Solve for:

X_L = ________

I_R = ________

I_L = ________

I_t = ________

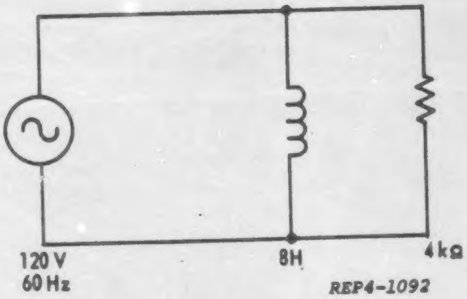
Z = ________

P_t = ________

P_a = ________

PF = ________

θ = ________


120 V
60 Hz
8H
4 kΩ
REP4-1092

Draw the current vectors.

MODULE SELF-CHECK

4. If the frequency of the generator in problem three is decreased, the applied voltage would

________________________.

5. Solve for:

I_L = ______

I_R = ______

I_t = ______

Z = ______

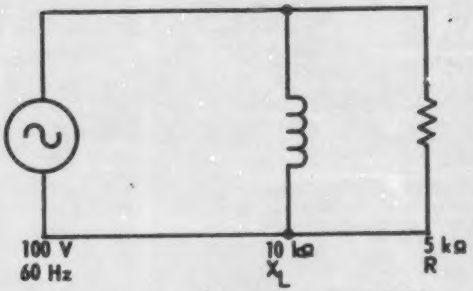
θ = ______

P_t = ______

P_a = ______

PF = ______

L = ______


100 V
60 Hz
10 kΩ
X_L
5 kΩ
R

REP4-1093

Draw the current vectors.

6. If the core of the coil in problem five is replaced by a material having a higher permeability, E_L would ________________ and I_t would ________________________.

7. Solve for:

Z = ______

X_C = ______

C = ______

E_a = ______

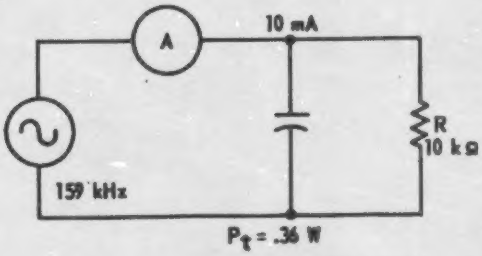
θ = ______

P_a = ______

PF = ______

I_R = ______

I_C = ______

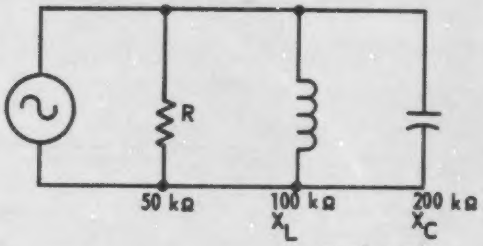

A
10 mA
159 kHz
R
10 kΩ
P_t = .36 W

REP4-1094

Draw the current vectors.

8. Solve for:

Z = ________


R
50 kΩ
100 kΩ
X_L
200 kΩ
X_C

REP4-1095

9. Solve for:

I_L = ________

I_C = ________

I_R = ________

I_t = ________

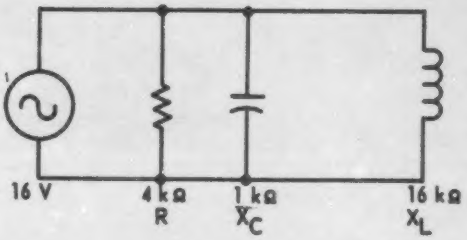
θ = ________

PF = ________

Z = ________

P_t = ________

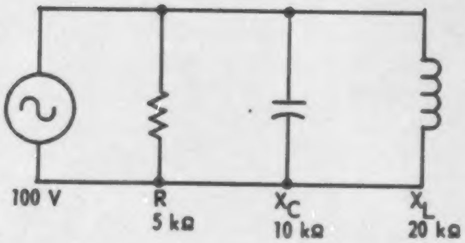
P_a = ________


16 V
4 kΩ
R
1 kΩ
X_C
16 kΩ
X_L

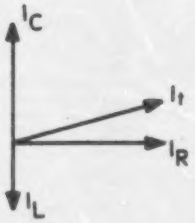
REP4-1096

Draw the current vectors.

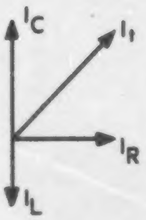
10. Select the vector diagram for this circuit.


100 V
R
5 kΩ
X_C
10 kΩ
X_L
20 kΩ

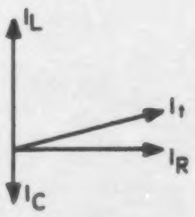
a. ___



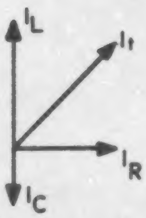
b. ___



c. ___



d. ___



REP4-1097

MODULE SELF-CHECK

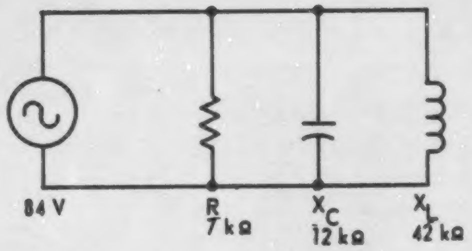
11. The total impedance is

    a. 4 k ohms

    b. 4.9 k ohms

    c. 6.4 k ohms

    d. 12 k ohms


84 V
R
7 kΩ
X_C
12 kΩ
X_L
42 kΩ

REP4-1098

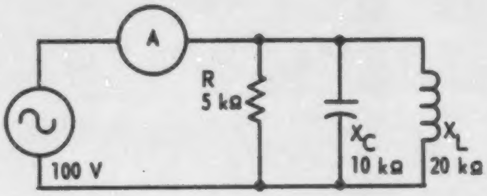
12. The reading on the ammeter has increased. What is the trouble?

    a. E_a has decreased.

    b. The resistance of the resistor has increased.

    c. The coil has opened.

    d. The capacitor has opened.


A
R
5 kΩ
X_C
10 kΩ
X_L
20 kΩ
100 V

REP4-1099

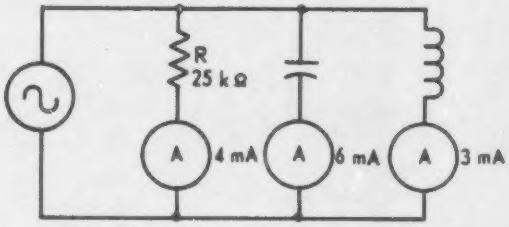
13. Total impedance is

    a. 5 k ohms.

    b. 10 k ohms.

    c. 15 k ohms.

    d. 20 k ohms.


R
25 kΩ
A
4 mA
A
6 mA
A
3 mA

REP4-1100

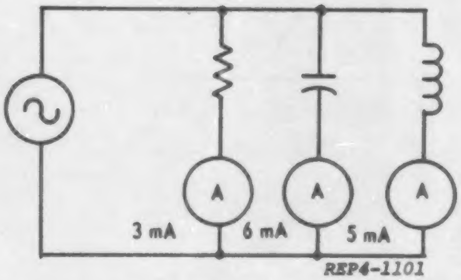
14. In this circuit,

    a. $R = X_C$.

    b. X_C is less than X_L.

    c. I_t lags E_a.

    d. I_R leads E_a.


A
A
A
3 mA
6 mA
5 mA

REP4-1101

15. Solve for:

I_R = ______

I_C = ______

E_a = ______

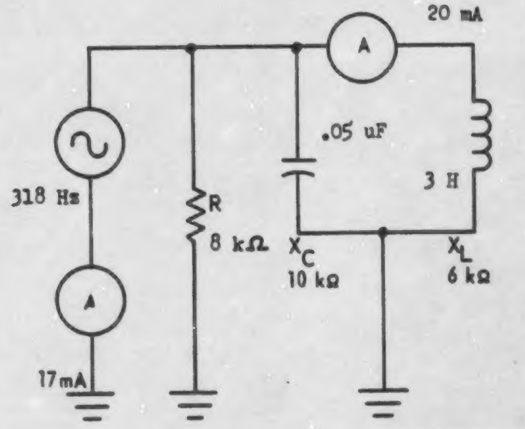
Z = ______

P_t = ______

P_a = ______

PF = ______

θ = ______


20 mA
A
.05 uF
3 H
318 Hz
R
8 kΩ
X_C
10 kΩ
X_L
6 kΩ
A
17mA

REP4-1102

Draw the current vectors.

16. Solve for:

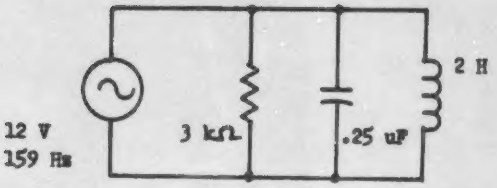
P_t = ______

P_a = ______

PF = ______

θ = ______

Z = ______

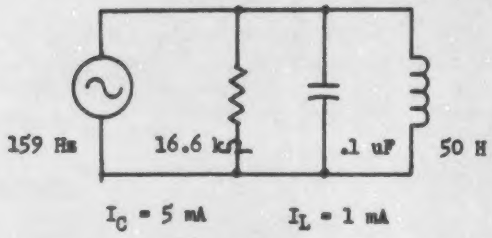

2 H
12 V
159 Hz
3 kΩ
.25 uF

Show vectors.

17. Solve for:

E_a = ______

Z = ______

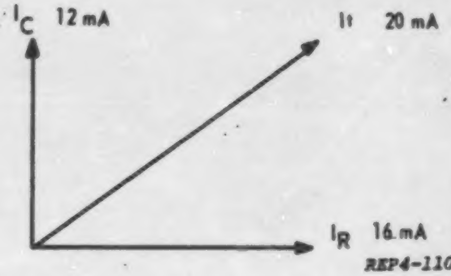

159 Hz
16.6 kΩ
.1 uF
50 H
I_C = 5 mA
I_L = 1 mA

Show vectors.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

ANSWERS TO MODULE SELF-CHECK

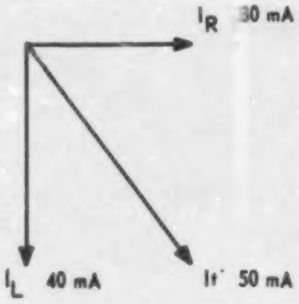
1. I_R = 16 mA P_t = 3072 mW
   I_C = 12 mA P_a = 3840 mVA
   I_t = 20 mA PF = .8
   Z = 9.6 kΩ θ = 36.8°
   X_C = 16 kΩ


I_C 12 mA
It 20 mA
I_R 16 mA

REP4-1103

2. I_C decreases and E_C remains the same.

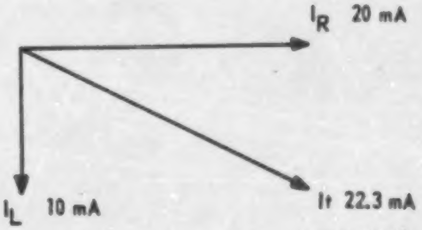
3. X_L = 3 kΩ P_t = 3.6 W
   I_R = 30 mA P_a = 6 VA
   I_L = 40 mA PF = .6
   I_t = 50 mA θ = 53.1°
   Z = 2.4 kΩ


I_R 30 mA
I_L 40 mA
It 50 mA

REP4-1104

4. Voltage would remain the same.

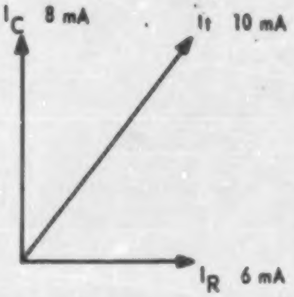
5. I_L = 10 mA P_t = 2 W
   I_R = 20 mA P_a = 2.23 VA
   I_t = 22.3 mA PF = .8960
   Z = 4.48 kΩ L = 26.5 H
   θ = 26.4°


I_R 20 mA
I_L 10 mA
It 22.3 mA

REP4-1105

6. E_L would remain the same and I_t would decrease.

7. Z = 6 kΩ P_a = 600 mVA
   X_C = 7.5 kΩ PF = .6
   C = 133 pF I_R = 6 mA
   E_a = 60 V I_C = 8 mA
   θ = 53.1°


I_C 8 mA
It 10 mA
I_R 6 mA

REP4-1106

ANSWERS TO MODULE SELF CHECK (Continued)

8. Z_t = 48.5 k Ω

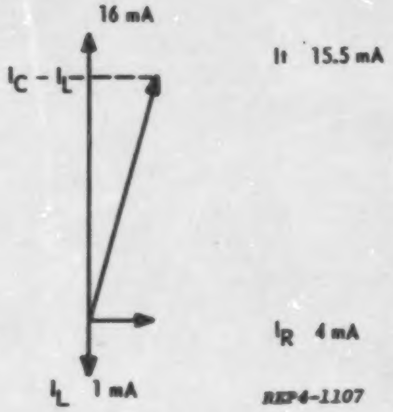
9. I_L = 1 mA PF = .2580

I_C = 16 mA Z = 1.03 k Ω

I_R = 4 mA P_t = 64 mW

I_t = 15.5 mA P_a = 248 mVA

θ = 75°


16 mA
It 15.5 mA
$I_C - I_L$
I_R 4 mA
I_L 1 mA

REP4-1107

10. a

11. c

12. c

13. d

14. b

15. I_R = 15 mA L = 3 H

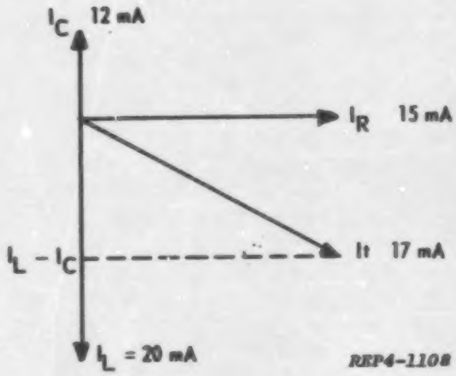
I_C = 12 mA P_t = 1800 mW

R = 8 k Ω P_a = 2040 mVA

E_a = 120 V PF = .8823

F = 318 Hz θ = 28.1°

Z = 7.05 k Ω


I_C 12 mA
I_R 15 mA
$I_L - I_C$
It 17 mA
I_L = 20 mA

REP4-1108

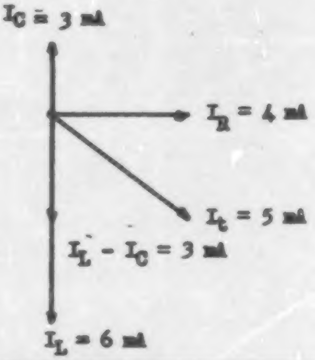
16. P_t = 48 mW

P_a = 60 mVA

PF = .8000

θ = -36.9°

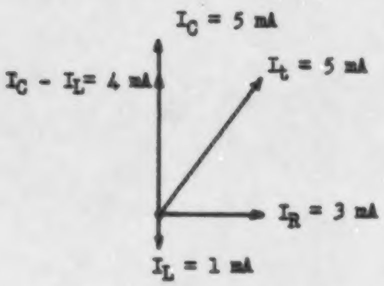
Z = 2.4 k Ω


I_C = 3 mA
I_R = 4 mA
I_t = 5 mA
$I_L - I_C$ = 3 mA
I_L = 6 mA

ANSWERS TO MODULE SELF-CHECK

17. $E_a = 50$ V

$Z = 10$ kΩ


$I_C = 5$ mA
$I_t = 5$ mA
$I_C - I_L = 4$ mA
$I_R = 3$ mA
$I_L = 1$ mA

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

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ATC PT 3AQR3X020-X
Prepared by Keesler TTC
KEP-PT-23

Technical Training

Electronic Principles (Modular Self-Paced)

Module 23

TROUBLESHOOTING SERIES AND PARALLEL RCL CIRCUITS

(Troubleshooting Capacitors and Inductors)

November 1975

AIR TRAINING COMMAND

7-7

Designed For ATC Course Use

ATC Keesler 6-2375

DO NOT USE ON THE JOB

RADAR PRINCIPLES BRANCH
Keesler Air Force Base, Mississippi

Guidance Package KEP-PT-23
3AQR3X020-X
November 1975

TROUBLESHOOTING SERIES AND PARALLEL RCL CIRCUITS

(TROUBLESHOOTING CAPACITORS AND INDUCTORS)

Module 23

This text is designed so that you will go through it step by step. Each step of instruction is designed to teach a small bit of information. Answers to the questions for each step are given at the top of the next even numbered page (blocked).

Read the information on the next even numbered page and respond as you are directed. Confirm your responses. Do not proceed until you have responded correctly. If you require assistance, see your instructor.

CONTENTS

TITLE	PAGE
Introduction	1
Troubleshooting Capacitors	2
Troubleshooting Inductors	13

Supersedes KEP-PT-23, 5 November 1974. Previous editions may be used.

TROUBLESHOOTING CAPACITORS AND INDUCTORS

INTRODUCTION

In electronic circuits, capacitors and inductors, like resistors, become defective and must be isolated and replaced. Defective resistors can usually be identified fairly conclusively with the ohmmeter; however, this is not the case with capacitors and inductors. It usually requires more careful attention to the troubleshooting procedures in order to identify defective capacitors and inductors than it does to detect defective resistors.

The troubleshooting procedures that can be used to isolate defective capacitors and inductors are presented in this text. The material is divided into two parts. The procedures for troubleshooting capacitors are in the first part and the procedures for troubleshooting inductors are in the second part.

The material is presented in steps with questions separating the steps. Respond to these questions and be sure you know the answers to these questions before advancing to the next step.

TROUBLESHOOTING CAPACITORS

What can cause a capacitor to become defective? Although there are others, these are some of the more frequent causes: (1) Voltage surges that exceed the WVDC rating of the capacitor produce an arc of current through the dielectric material, partially or completely destroying the dielectric; (2) high temperature or the frequent changes in temperature cause expansion and contraction within the capacitor, causing the leads to separate from the plates; (3) moisture gets inside the capacitor (paper capacitors are very susceptible to moisture) and destroys the dielectric material; and (4) some dielectric material - usually the electrolyte in the electrolytic capacitor - deteriorates with age or long storage time.

More important than the causes of capacitor failure is the types of failures that they produce. Voltage surges and moisture in a capacitor normally cause a SHORTED or LEAKY condition. High temperature or frequent changes in temperature sometimes cause an OPEN condition. The three types of failures discussed in this text are: (1) the SHORTED capacitor; (2) the OPEN capacitor; and (3) the LEAKY capacitor.

Some of the test instruments that can be used to troubleshoot capacitors are the capacitor checker (which is rarely available to the technician), voltmeter, ammeter, and ohmmeter.

Usually, the OHMMETER is preferred over all the other test instruments. It is the easiest to use and will yield more information about the condition of a capacitor in less time than any of the other instruments. The OHMMETER will be used in all further discussion on the troubleshooting of capacitors and the ohmmeter section of the PSM-6 will be used in all examples.

QUICK QUIZ 1.

1. This text will discuss the ________________ that can be used to isolate defective capacitors.
2. In troubleshooting capacitors, the three most common types of failures likely to be encountered are the __________, __________, and ______________ capacitor.
3. The test instrument usually preferred over other types to troubleshoot capacitors is the:

   a. voltmeter c. ohmmeter

   b. ammeter d. oscilloscope

Check your answers on the next even numbered page.

When used to check capacitors, the ohmmeter has a number of limitations that one must know in order to make the best use of the ohmmeter. These limitations are: (1) the ohmmeter cannot be used to measure the amount of capacitance (in farads) of a capacitor; (2) capacitors with very SMALL capacitance (less than .001 microfarads) cannot be effectively checked for an OPEN condition; (3) the LEAKAGE

ANSWERS TO QUICK QUIZ 1.

1. procedures
2. open, short, and leaky
3. c

test on an electrolytic capacitor is usually not reliable (all electrolytic capacitors have some allowable leakage according to their capacitance); (4) capacitors with a WVDC rating less than the internal power source of the ohmmeter should not be checked; and (5) capacitors are not checked at their full WVDC rating.

If the condition of a suspect capacitor cannot be determined by using the ohmmeter, the normal procedure is to replace it with one known to be GOOD. This usually requires less time and effort than to obtain the test equipment necessary to perform elaborate checks on a relatively inexpensive component.

QUICK QUIZ 2.

1. The ohmmeter cannot be used to measure the ____________ of a capacitor.
2. Capacitors with very _______ capacitance cannot be effectively checked for an open condition with the ohmmeter.
3. If the condition of a suspect capacitor cannot be determined with the ohmmeter, it should be replaced with a capacitor known to be _____________.

Check your answers on the next even numbered page.

The order in which a capacitor is checked for a SHORT, OPEN, or LEAKY condition is not important. To establish a pattern for the purpose of explanation only, the ensuing discussions will be in the following order: (1) the check for a SHORTED condition; (2) the check for an OPEN condition; and (3) the check for a LEAKY condition. A capacitor that is neither SHORTED, OPEN, nor LEAKY can usually be considered to be a GOOD capacitor.

Before making any tests with the ohmmeter, it is VERY IMPORTANT that power be removed from the circuit being checked and all capacitors should be discharged by connecting a wire across their terminals. Also, for the ohmmeter indications to be meaningful, the capacitor must be isolated from the other components in the circuit.

If the capacitor is connected in series with other components, it can be isolated by opening the circuit at any point. In other words, the current from the ohmmeter can have only one path, into and out of the capacitor. In a simple series circuit as shown in Figure 1-1, the capacitor is isolated and the power source is removed whenever the switch is open. If no switch is provided, the circuit must be disconnected from the power source.

ANSWERS TO QUICK QUIZ 2.

1. capacitance.
2. small.
3. good.

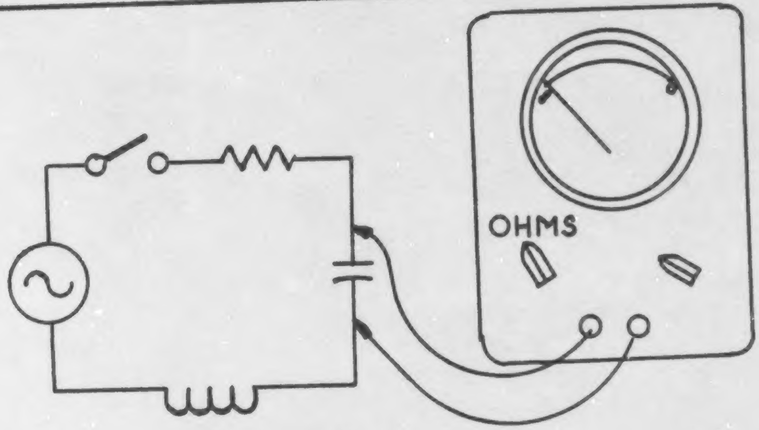


Figure 1-1

Figure 1-2 is a simple parallel circuit. Power can be removed from the circuit by opening the switch. If no switch is provided, the circuit must be disconnected from the source; also, one lead of the capacitor MUST be disconnected from the circuit to isolate the capacitor.

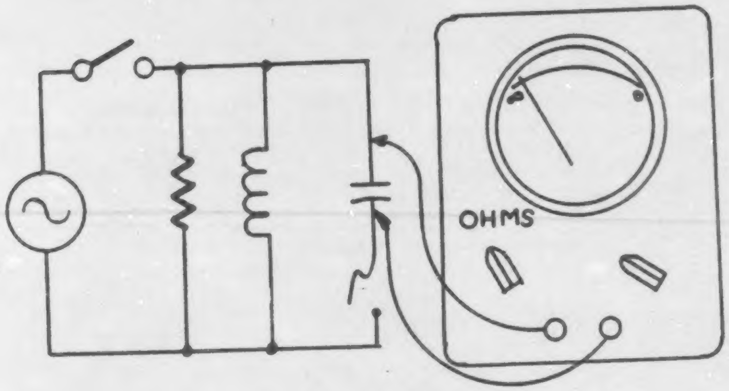


Figure 1-2

QUICK QUIZ 3.

1. To prevent damaging the ohmmeter, ____________ must be removed from the circuit to be checked.
2. For the ohmmeter reading to be meaningful, the capacitor must be ______________.
3. A capacitor that is neither shorted, open, nor leaky can usually be considered to be a ________________ capacitor

Check your answers on the next even numbered page.

After the power has been removed from the circuit and the capacitor isolated from the other components, the next step is to prepare the ohmmeter so that it will indicate the smallest amount of resistance. This is done by setting the range switch to the lowest-ohm position (RX1) and calibrating the meter; then, the ohmmeter leads should be connected to the capacitor as shown in Figure 1-3. It is not necessary to observe polarity.

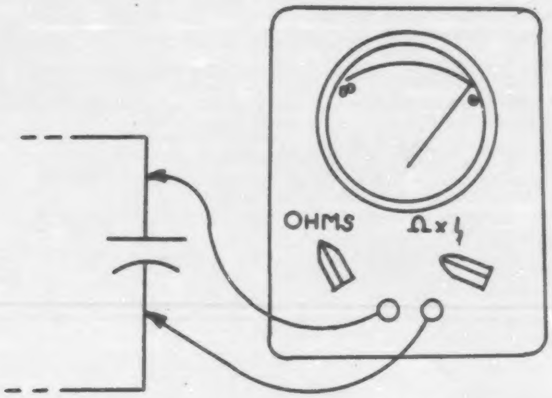


Figure 1-3

ANSWERS TO QUICK QUIZ 3.

1. power.
2. isolated.
3. good.

A reading of ZERO OHM indicates that the dielectric material has completely broken down and is allowing current to pass between the plates. This condition is termed a SHORTED capacitor.

The next check is for an OPEN capacitor (.001 µF or larger). Prepare the ohmmeter by setting the range switch to the highest-ohm position (R X 10,000 ohms) and calibrating the meter. As in the previous step, the ohmmeter is connected to the capacitor; however, it is very important that the ohmmeter needle be observed very closely at the instant the leads are connected to the capacitor. This step should be repeated two or three times, reversing the ohmmeter leads to the capacitor each time the step is repeated. If the ohmmeter needle remains at infinity and DOES NOT deflect up-scale as shown in Figure 1-4, the capacitor is OPEN.

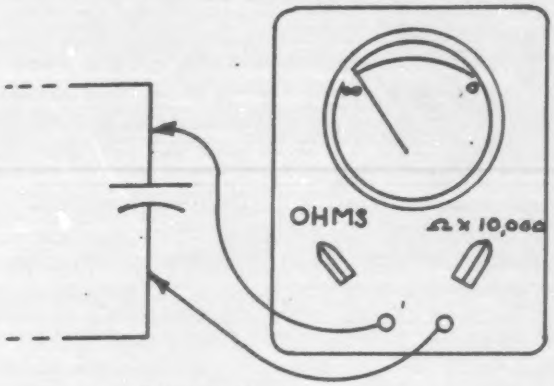


Figure 1-4

QUICK QUIZ 4.

1. To check a capacitor for a short, the ohmmeter range switch should be set to the:

   a. ΩX1 position. c. ΩX1000 position.

   b. ΩX10 position. d. ΩX10,000 position.

2. A zero-ohm reading on the ohmmeter indicates a _________ condition for a capacitor.

3. To check a capacitor for an open, the ohmmeter range switch should be set to the:

   a. ΩX1 position. c. ΩX1000 position

   b. ΩX10 position. d. ΩX10,000 position.

4. When troubleshooting a capacitor, the needle of the ohmmeter remains at infinity and does not deflect up-scale. The capacitor is:

   a. shorted. b. open. c. good.

Check your answers on the next even numbered page.

The last check to be performed on a capacitor is probably the most important test of all--the test for LEAKAGE. Since no dielectric material is a perfect insulator, all capacitors have an allowable leakage (current flow) between their plates. Only when this leakage becomes excessive is a capacitor considered to be defective. This leakage varies directly according to the capacitance of a capacitor. The ohmmeter will indicate this leakage as resistance; therefore, since most capacitors have very small leakage currents, the ohmmeter will indicate a very HIGH resistance for a GOOD capacitor.

ANSWERS TO QUICK QUIZ 4.

1. a.
2. shorted
3. d
4. b

To test for LEAKAGE, the ohmmeter is set to the highest ohm position (RX10,000 ohm) and connected to the capacitor in the same manner as for the SHORT, or OPEN test. Any steady resistance reading on the ohmmeter as shown in Figure 1-5 indicates that the capacitor being checked is a LEAKY capacitor. Remember, this test DOES NOT apply to an electrolytic capacitor. For the LEAKAGE test the hands must not touch the capacitor leads.

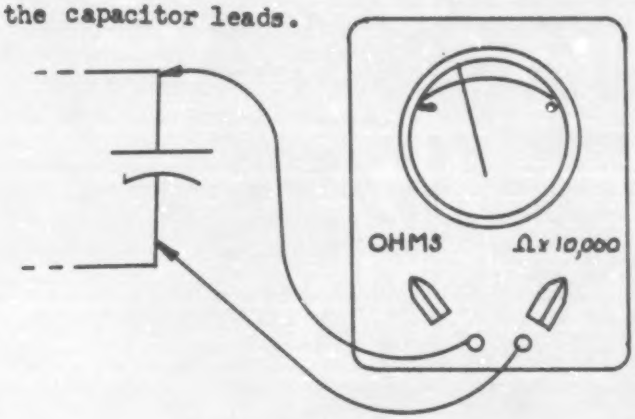


Figure 1-5

A GOOD capacitor can also be checked because a good capacitor will give a definite indication on the ohmmeter. As for the open and leakage check, the ohmmeter is set to the RX10,000 ohm position and the ohmmeter needle observed very closely at the instant the leads are connected to the capacitor. As shown in Figure 1-6, the needle should deflect up-scale (toward zero ohm) and then drop back to infinite resistance. The leads should be reversed two or three times to insure that the capacitor is discharged.

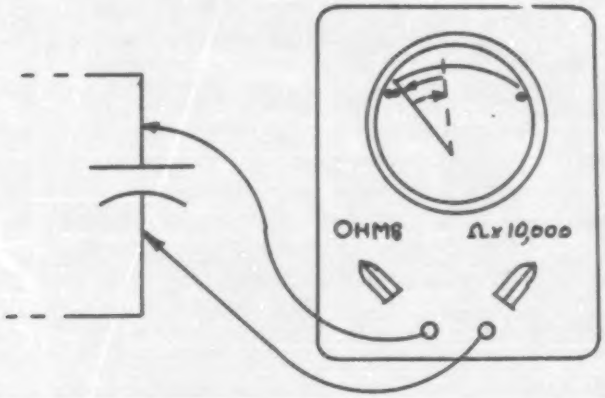


Figure 1-6

QUICK QUIZ 5.

1. Leakage current is read on the ohmmeter as:

   a. voltage b. current. c. resistance.

2. To test for leakage, the ohmmeter should be set to the:

   a. ΩX1 position c. ΩX1000 position.

   b. ΩX10 position. d. ΩX10,000 position.

3. Which reading indicates a leaky capacitor?

   a. zero ohm b. 5000 ohm c. infinity.

4. With the ohmmeter range on RX10,000 which capacitor would cause the ohmmeter needle to deflect up-scale and then drop back to infinity?

   a. A good capacitor. c. A shorted capacitor.

   b. a leaky capacitor. d. An open capacitor.

Check your answers on the next even numbered page.

ANSWERS TO QUICK QUIZ 5.

1. c
2. d
3. b
4. a

In summary, as a capacitor checker, the ohmmeter is a very useful instrument. It cannot be used to check all capacitors for each type of failure. However, a capacitor that cannot be checked completely should be replaced with one known to be GOOD. Again, in preparing the circuit, remove power to the circuit and isolate the component. In many cases, to isolate the capacitor, simply remove it from the circuit. Remember, a zero-ohm reading on the ohmmeter indicates a SHORTED capacitor; an infinite reading with no momentary up-scale deflection of the ohmmeter needle indicates an OPEN capacitor; a steady resistance reading other than infinity or zero-ohm, indicates a LEAKY capacitor; and a reading of infinity after a momentary up-scale deflection indicates a GOOD capacitor.

TROUBLESHOOTING INDUCTORS

An inductor is a circuit component designed so that inductance is its most important property. Coils and chokes are designed so that they present a specified amount of inductance to a circuit; however, audio and power transformers, voice coils in speakers, field and armature windings in motors for all practical purposes of troubleshooting can be treated exactly the same as coils and chokes.

Inductors do fail and since they are an integral part of many electronic circuits, they must be checked to determine their condition. The most common types of failures that occur in inductors are: (1) OPEN windings; (2) SHORTED turns; (3) winding to core shorts; and (4) SHORTS between windings.

Although there are test instruments designed specifically for testing the different types of inductors--chokes, transformers, motor windings, etc. -- usually the OHMMETER is used to perform the preliminary checks on an inductor suspected of being defective.

Again, to make the best use of the OHMMETER, its limitations must be known. As an inductor tester, its limitations are these: (1) the ohmmeter CANNOT be used to measure the inductance of an inductor; and (2) shorted turns in inductors are difficult to locate with the ohmmeter.

QUICK QUIZ 6.

1. The test instrument that is usually used to make preliminary checks on inductors suspected of being defective is the:

   a. ohmmeter. b. voltmeter. c. ammeter.

2. The ohmmeter CANNOT be used to measure the ____________ of an inductor.

3. Usually, a defective inductor has:

   a. increased in inductance.

   b. shorted or open winding.

   c. become resonant.

Check your answers on the next even numbered page.

The first step in any troubleshooting procedure in which the ohmmeter is utilized is to REMOVE power to the circuit. Secondly, isolate the inductor from the other components in the circuit in the same manner as when troubleshooting capacitors.

After the power has been removed from the circuit and the inductor isolated from the other components, the next step is to prepare the ohmmeter so that it will indicate the maximum amount of resistance. This is done by setting the range switch to the highest-ohm position (RX10,000) and calibrating the meter; then, the ohmmeter should be connected to the inductor as shown in Figure 2-1.

An infinite resistance reading on the ohmmeter indicates that the inductor is definitely OPEN.

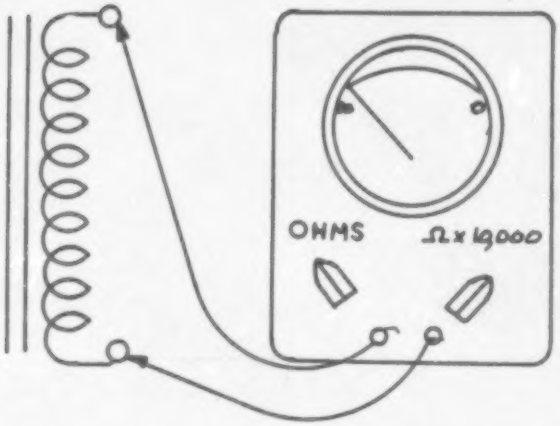


Figure 2-1

QUICK QUIZ 7.

1. Before troubleshooting inductors with an ohmmeter, the ____________ must be removed and the component __________________.

2. To check inductors for open windings, the ohmmeter range switch must be set to the:

   a. ΩX10 position.
   b. ΩX100 position.
   c. ΩX1000 position.
   d. ΩX10,000 position.

3. A reading of infinite resistance on the ohmmeter indicates that an inductor has:

   a. open winding.
   b. shorted winding.
   c. leaky winding.

Check your answers on the next even numbered page.

ANSWERS TO QUICK QUIZ 6.

1. a
2. inductance.
3. b

ANSWERS TO QUICK QUIZ 7.

1. power, isolated.
2. d
3. a

As stated previously, one limitation of the ohmmeter is that it cannot be used to check all inductors for shorted turns. For example, an inductor wound with a few turns of large copper wire, such as RF coils, will indicate zero resistance on the ohmmeter even on the Ω X1 range. Thus a shorted turn in this type of inductor cannot be detected with the ohmmeter. However, some inductors CAN be checked for shorted turns. If the winding resistance is sufficiently high to be measured with the ohmmeter and if the resistance is known, an inductor of this type can be checked for shorted turns.

Figure 2-2 shows an example of a transformer that has shorted turns in the secondary winding. The ohmmeter indicates 500 ohms which is a decrease of 250 ohms from the 750 ohms specified for the secondary winding of the transformer. A decrease in resistance much less than the amount shown in Figure 2-2 would still indicate shorted turns in the transformer—even a decrease of a few ohms of resistance.

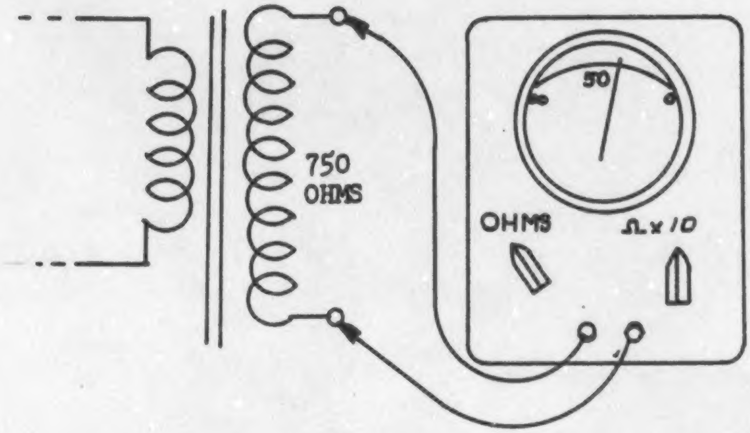
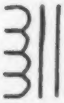

750
OHMS
50
OHMS
Ω x 10

Figure 2-2

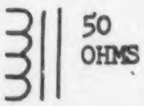
QUICK QUIZ 8.

1. Select the inductor(s) that could be checked for shorted turns with the ohmmeter:

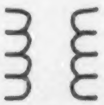
a.



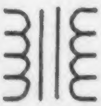
b.



c.



d.



2. An (A) (increase/decrease) in winding resistance indicates shorted turns.

Check your answers on the next even numbered page.

ANSWERS TO QUICK QUIZ 8.

1. b

2. a decrease.

Another type of short that can be detected with the ohmmeter is a short between the turns and core material. Of course, this type of short can only occur in an inductor having an iron core. To check an inductor for winding-to-core shorts, connect the ohmmeter leads between the core and winding as shown in Figure 2-3. Since GOOD inductors have infinite resistance between the core and windings, any resistance reading on the ohmmeter other than infinity indicates a defective inductor.

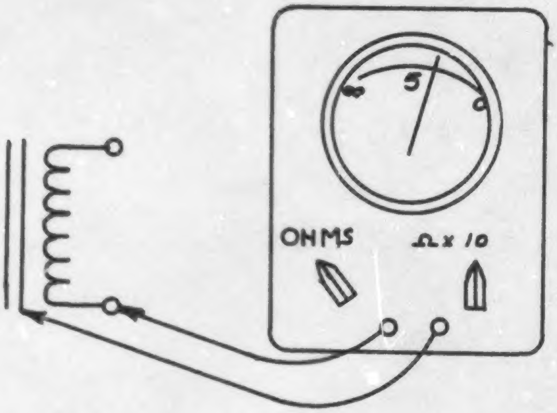


Figure 2-3

Last, a type of short that occurs in inductors with multiple windings, such as transformers, is the short between windings. In transformers, the windings are usually wound very tightly, one upon the other; therefore, if the insulating material should fail, a short will occur between the windings. Shorts between windings can be detected with the ohmmeter. To test for shorts between windings of an inductor, connect the ohmmeter leads between windings as shown in Figure 2-4. A resistance measurement must be made between each set of windings in turn. GOOD transformers have infinite resistance between windings; therefore, any resistance reading other than infinite indicates a defective transformer. (See Figure 2-4)

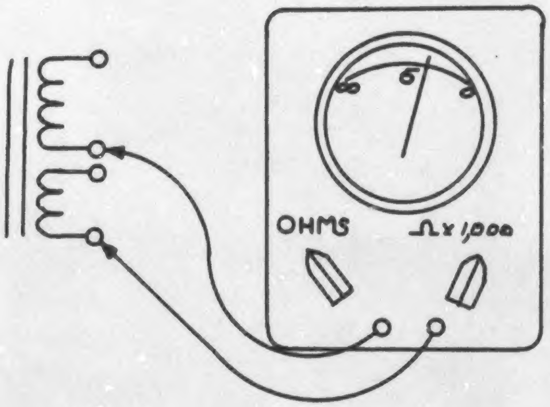


Figure 2-4

QUICK QUIZ 9.

1. A good inductor should have (infinite, low) resistance between its core and windings.

2. The ohmmeter (can, cannot) be used to detect shorts between the windings of an inductor with multiple windings.

Check your answers on the next even numbered page.

How do you troubleshoot an inductor suspected of having a short and yet the ohmmeter indications are inconclusive? If the inductor is expensive, requires a great amount of time to replace, and is not readily available, check all the other components associated with the inductor--if they are good, the inductor must be defective. An excellent check for any inductor suspected of being defective is to substitute it with a NEW inductor.

QUICK QUIZ 10.

1. When troubleshooting inductors with the ohmmeter, it is difficult to detect:
    a. open windings.
    b. shorted turns.
2. Name ONE method of checking an inductor without the use of an ohmmeter. ______________________________

Check your answers on the next even numbered page.

NOTES

ANSWERS TO QUICK QUIZ 9.

1. infinite.

2. can.

ANSWERS TO QUICK QUIZ 10.

1. b

2. substitution.

This programmed text is not complete until after you have completed laboratory exercise 23-1. Upon completion of the laboratory exercise steps, confirm your answers by using the ohmmeter to check each component. Remember, power must be removed and the component isolated (disconnected) before the ohmmeter is used.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

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PREPARE THE MAN

ATC ST 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-24

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 24

SERIES RESONANCE

1 October 1975

AIR TRAINING COMMAND

7-7

Designed For ATC Course Use

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Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-24
October 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 24

SERIES RESONANCE

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

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OVERVIEW

1. SCOPE: If the frequency applied to a series RCL circuit is varied, the inductive reactance can be made to equal the capacitive reactance. When this occurs, we have resonance. This module discusses the conditions that exist when the series circuit is resonant. Resonant circuits are used in radio, radar, and telephone circuits to separate signals in terms of frequency. Practical training to determine bandwidth, bandpass, and resonant frequency completes the module.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given the response curve of a series RCL circuit, compare the magnitude of current flow at resonance and off-resonance.

b. Given a series RCL circuit, and vector representations of current and voltage, select the representation which shows current and voltage relationships

(1) below resonance.
(2) above resonance.
(3) at resonance.

c. Given a series RCL circuit and formulas, determine the effects on current, impedance, and phase angle by varying individually

(1) frequency.
(2) resistance.
(3) capacitance.
(4) inductance.

d. Given component values of a series RCL circuit, calculate the resonant frequency.

e. Using a series RCL circuit connected on a trainer, signal generator, and multimeter, determine the half power points, bandwidth, bandpass, and resonant frequency.

Supersedes KEP-GP-24, 15 May 1975 which may be used until stock is exhausted.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text, Vol III

AUDIO-VISUALS:

Television Lesson, Series RCL Circuits (Resonance), TVK 30-260

LABORATORY EXERCISE:

Series Resonance 24-1

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK. IF NOT, SELECT ONE OF THE RESOURCES AND BEGIN STUDY. CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the reference materials as directed.

Return to this guide and answer the questions.

Confirm your answers at the back of this Guidance Package.

If you experience any difficulty, contact your instructor.

Begin the program.

A. Turn to Student Text Volume III and read paragraphs 5-1 through 5-14. Return to this page and answer the following questions.

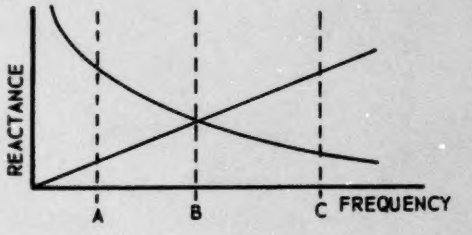
1. What is the definition of series resonance?

2. Referring to the graph, which point is considered to be resonance?

______ a. Point A.

______ b. Point B.

______ c. Point C.



REP4-1124

3. How does a series RCL circuit act when a frequency below the resonant frequency is applied:

______ a. Capacitive.

______ b. Inductive.

______ c. Resistive.

4. How does a series RCL circuit act when a frequency above the resonant frequency is applied?

______ a. Capacitive.

______ b. Inductive.

______ c. Resistive.

5. Which of the following is NOT a condition or characteristic of series resonance?

______ a. $X_C = X_L$

______ b. $Z = R$

______ c. Z is minimum

______ d. I is maximum

______ e. $E_a = E_C$

______ f. $E_R = E_a$

______ g. $E_C = E_L$

______ h. $\theta = 0^\circ$

______ i. $P_a = P_t$

6. How does a series RCL circuit act at the resonant frequency?

______ a. Capacitive.

______ b. Inductive.

______ c. Resistive.

7. If opposition to current at resonance is minimum, what is the condition of current in the series RCL circuit at resonance?

8. For any given RCL circuit, how many different frequencies will cause a resonant condition?

______ a. One.

______ b. Two.

______ c. Three.

9. If you have an RCL circuit acting capacitively, what three parameters can be changed to make the circuit act as a resonant circuit?

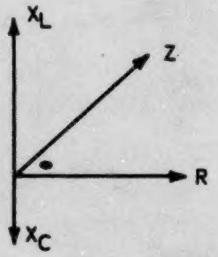
____

____

____

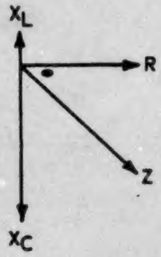
10. Identify the following vectors and indicate whether they represent a series RCL circuit at resonance, above resonance, or below resonance.

a. ______________________________

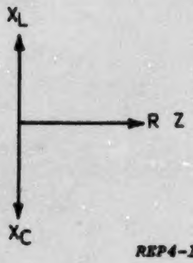


REP4-1126

b. ______________________________



c. ______________________________



REP4-1125

CONFIRM YOUR ANSWERS

____

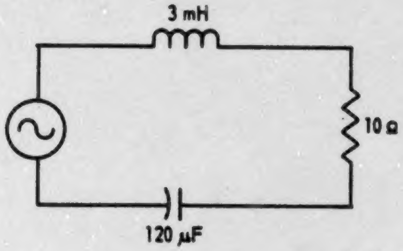
B. Turn to Student Text Volume III and read paragraphs 5-11 through 5-22. Return to this page and answer the following questions.

1. Solve for the resonant frequency when L is 10 mH and C is 1 μF.

2. Solve for the resonant frequency when L is 2.5 mH and C is 16 µF.

3. Solve for the resonant frequency when L is 5µH and C is 5pF.

4. Solve for the resonant frequency in the following circuit.



REP4-1127

5. The following chart is a graphic illustration of the different quantities in a series RCL circuit. Match each curve with the quantity it represents.

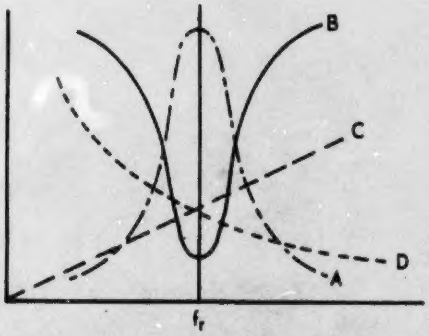
______ a. Curve A (1) I

______ b. Curve B (2) X_C

______ c. Curve C (3) Z

______ d. Curve D (4) X_L

(5) E



REP4-1128

CONFIRM YOUR ANSWERS.

C. Turn to Student Text Volume III and read paragraphs 5-23 through 5-43. Return to this page and answer the following questions.

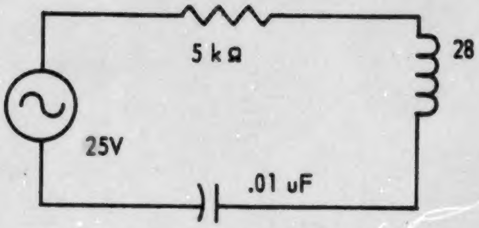
1. Solve for:

f_r = ____________________

Z = ____________________

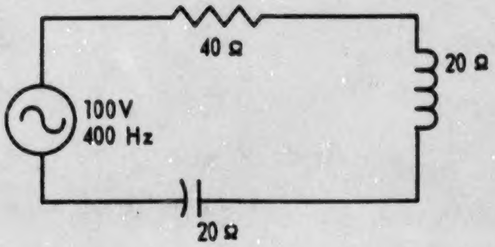
I = ____________________

θ = ____________________



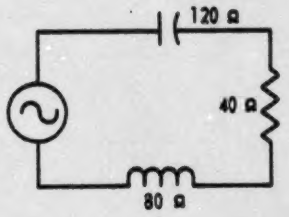
REP4-1129

2. Draw the vectors for this circuit.

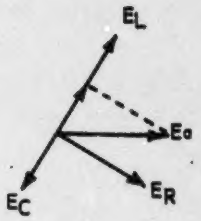


REP4-1130

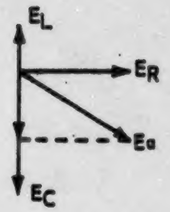
3. Select the proper vectors for this circuit. (E_a is to be used as a reference.)


120 Ω
40 Ω
80 Ω

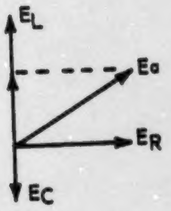
______ a.



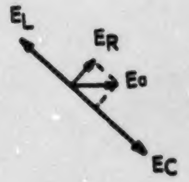
______ b.



______ c.



______ d.



4. The circuit in question 3 is acting:

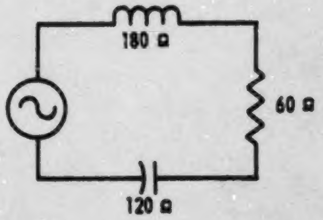
______ a. Capacitively and operating above resonance.

______ b. Inductively and operating above resonance.

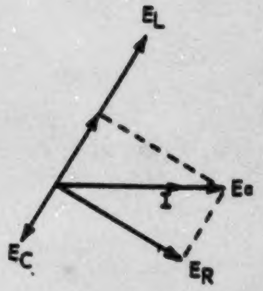
______ c. Capacitively and operating below resonance.

______ d. Inductively and operating below resonance.

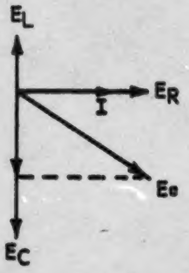
5. Select the proper vectors for this circuit. (I is to be used as a reference.)


180 Ω
60 Ω
120 Ω

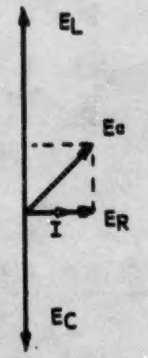
______ a.



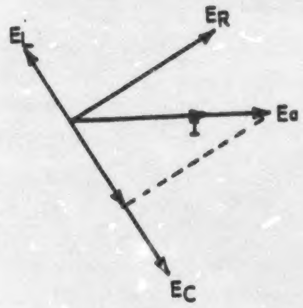
______ b.



______ c.



____ d.



6. The circuit in question 5 is acting:

____ a. Capacitively, and operating above resonance.

____ b. Inductively, and operating above resonance.

____ c. Capacitively, and operating below resonance.

____ d. Inductively, and operating below resonance.

7. What are the HALF POWER POINTS?

8. What formula is used to determine the current at the HALF POWER POINTS?

____ a. .637 times I maximum.

____ b. .707 times I maximum.

____ c. 1.414 times I maximum.

____ d. 1.57 times I maximum.

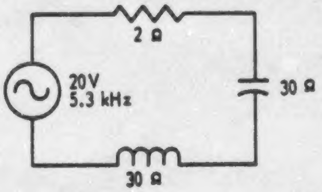
9. What is meant by the term BANDWIDTH?

10. What is meant by the term BANDPASS?

CONFIRM YOUR ANSWERS

D. Turn to Laboratory Exercise 24-1. This exercise will familiarize you with the procedure for determining the bandwidth, bandpass, half power points, and resonant frequency of a series RCL circuit. Return and continue with this program upon completion of this exercise.

E. Turn to Student Text Volume III and read paragraphs 5-44 through 5-47. Return to this page and answer the following questions.



REP4-1135

1. Using the circuit above, fill out the chart below. Indicate an increase, decrease, or remain the same for each value as frequency, resistance, capacitance, or inductance is individually varied as indicated:

Increase ↑
Decrease ↓
Remain the same →

	Z	I	θ
FREQ ↑			
RES ↓			
CAP ↑			
IND ↓			

CONFIRM YOUR ANSWERS

LABORATORY EXERCISE 24-1

OBJECTIVE: Using an ammeter and formulas, determine the bandwidth, bandpass, half power point, and resonant frequency of a series RCL circuit connected on a trainer.

EQUIPMENT:

1. AC Inductor and Capacitor Trainer 5967
2. Multimeter ME-70A/PSM-6
3. Sine-Wave Generator 4864
4. Meter Panel 4568

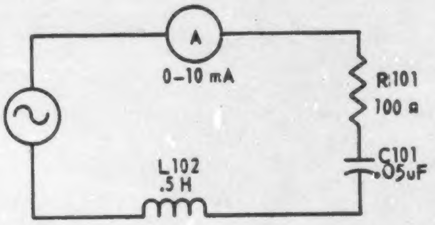
REFERENCES:

1. Student Text Volume III, Chapter 5
2. Student Handout, KEP 108

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

1. Construct the circuit in the diagram.



REP4-1137

2. Set the generator FREQ MULTIPLIER to 10 and the FREQUENCY (CPS) dial to midscale.

3. Adjust the sine wave output of the generator to maximum.

4. While observing the ammeter, slowly rotate the FREQUENCY dial to the position that produces the maximum current. This is the resonant frequency of the circuit.

5. Record the resonant frequency on the chart at the bottom of this page.

6. Reduce the sine wave output of the generator until the current meter reads 4 mA. Plot this maximum current value on the f_r line.

7. Calculate the current value at the half power point. ________________ mA

CONFIRM YOUR ANSWERS

8. Increase the frequency in 50 Hz steps and plot the current at each frequency, until the current decreases to the half-power point value.

9. Return the dial to the resonant frequency.

10. Decrease the frequency in 50 Hz steps and plot the current at each frequency, until the current reaches the half-power point value.

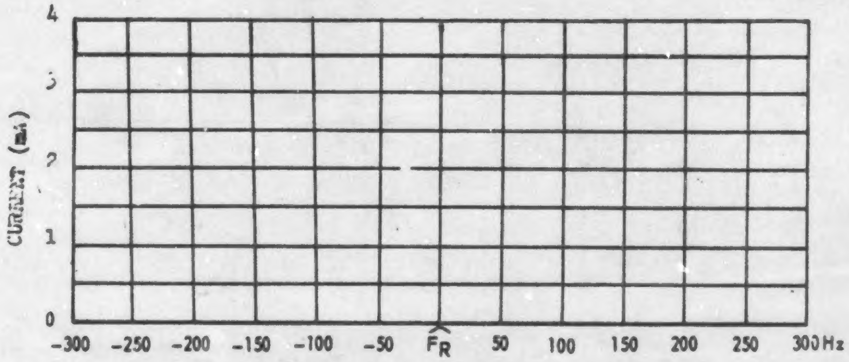
11. Find the bandpass from the chart.

Bandpass = ________________

12. Determine the bandwidth from the chart.

Bandwidth = ________________

CONFIRM YOUR ANSWERS



RESONANT FREQUENCY = ________________

REP4-1139

MODULE SELF-CHECK

QUESTIONS:

1. Series resonance occurs in an RCL circuit when:

____ a. the phase angle between X_C and R is exactly 90°.

____ b. $X_L = X_C$.

____ c. X_L is exactly five times as great as X_C.

____ d. X_C is exactly five times as great as X_L.

2. At resonance in a series RCL circuit

____ a. current is minimum.

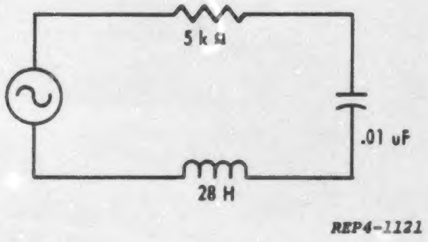
____ b. impedance is maximum.

____ c. voltage across the coil is minimum.

____ d. current is maximum.

3. Solve for:

f_r = ____________________



4. At resonance angle theta equals

____ a. 0°.

____ b. 45°.

____ c. 90°.

____ d. 180°.

5. Solve for the resonant frequency when L is .3 mH and C is 12 pF.

f_r = ____________________

6. If resonant current is 10 mA, what is the half power point current?

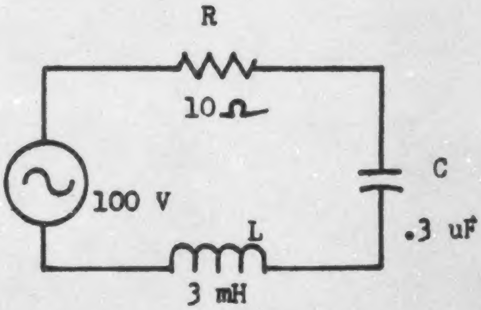
____ a. 2.5 mA

____ b. 5 mA

____ c. 7mA

____ d. 10mA

7. Solve for:



f_r = ____________________

Z= ____________________

I = ____________________

θ = ____________________

8. Reference problem 7. A voltmeter placed across both the capacitor and the coil while the circuit is at resonance would indicate:

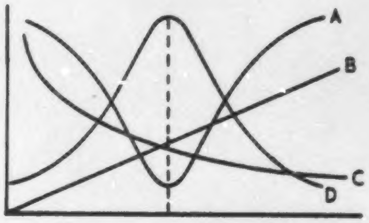
_____ a. 0 volts.

_____ b. 500 volts.

_____ c. 1000 volts.

_____ d. 2000 volts.

9. Identify the curve representing current below, at, and above resonance.



REP4-1140

_____ a. Curve A

_____ b. Curve B

_____ c. Curve C

_____ d. Curve D

10. If the frequency to a series resonant circuit is increased, what effect would there be on the following values?

Increase (↑)
Decrease (↓)
Remain the same (→)

Z _____

I _____

θ _____

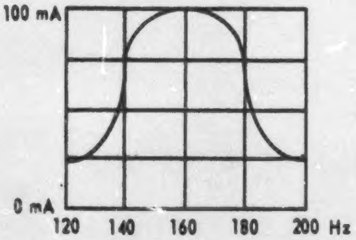
11. Using the figure below, what is the:

f_r = _____

BW = _____

BP = _____

HPP Current = _____



REP4-1141

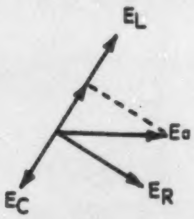
12. The following vector diagram represents the current and voltage relationships in a series RCL circuit. The circuit is acting:

_____ a. capacitively and is above resonance.

_____ b. inductively and is above resonance.

_____ c. capacitively and is below resonance.

_____ d. inductively and is below resonance.



CONFIRM YOUR ANSWERS ON THE LAST PAGE OF THIS TEXT.

ANSWERS TO A - ADJUNCT GUIDE

1. The frequency where the capacitive reactance (X_C) equals the inductive reactance (X_L).

2. b
3. a
4. b
5. e
6. c.

7. Maximum. This is a very important characteristic of resonance and an important point to remember.

8. a

9. Increase frequency, capacitance or inductance.

10. a. above resonance
    b. below resonance
    c. at resonance

If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. 1.59 kHz
2. 795 Hz
3. 31.8 MHz
4. 265 Hz

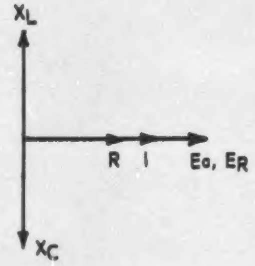
5. a. (1) Current (I)
   b. (3) Impedance (Z)
   c. (4) Inductive Reactance (X_L)
   d. (2) Capacitive Reactance (X_C)

If you missed ANY questions, review the material before you continue.

ANSWERS TO C - ADJUNCT GUIDE

1. $f_r = 300$ Hz
   $Z = 5$ kOhms
   $I = 5$mA
   $\theta = 0°$

2.



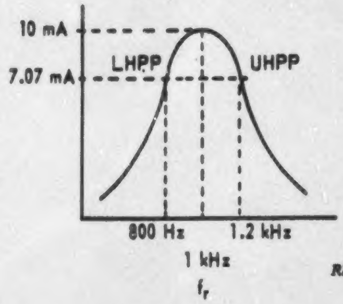
REP4-1133

3. d
4. c
5. c
6. b

7. The upper and lower points on the current response curve where the current is at 70.7% of the peak current.

8. b

9. Bandwidth is the number of cycles between the lower half-power point and the upper half-power point; i.e.,



REP4-1134

UHPP = 1.2 kHz
LHPP = 800 Hz
Bandwidth = 400 Hz

(Bandwidth can also be determined by the following formula:)

$$BW = f_r/Q$$

10. Bandpass is the actual frequencies from the Lower Half-Power point to the Upper Half-Power Point. In the example of number 9 above, bandpass is 800 Hz to 1200 Hz.

If you missed ANY questions, review the material before you continue.

ANSWERS TO E - ADJUNCT GUIDE

1.

	Z	I.	O
FREQ ↑	↑	↓	↑
RES ↓	↓	↑	→
CAP ↑	↑	↓	↑
IND ↓	↑	↓	↑

If you missed ANY questions, review the material before you continue.

ANSWER TO LABORATORY EXERCISE:

7. Use the formula Half Power Point Current = .707 x I_{max}. 2.8 mA

If you missed the question, ask your instructor for assistance.

11. BP = f_{lo} to f_{hi}, where f_{lo} = frequency at the low half-power point and f_{hi} = frequency at the high half-power point.

12. BW = $f_{hi} - f_{lo}$

Have your instructor check your answers.

If you missed ANY questions, ask your instructor for assistance.

ANSWERS TO MODULE SELF-CHECK

1. b
2. d
3. 300Hz
4. a
5. 2.65 MHz
6. c

7. $f_r = 5.3$ kHz
   Z = 10
   I = 10A
   $\theta = 0°$

8. a
9. d

10. Z ↑ I ↓ θ ↑

11. $f_r = 160$ Hz
    BW = 40 Hz
    BP = 140Hz to 180 Hz
    HPP Current = 70.7 mA

12. b

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-25

Technical Training

Electronic Principles (Modular Self-Paced)

Module 25

PARALLEL RESONANCE

November 1975

AIR TRAINING COMMAND

7-7

Designed For ATC Course Use

DO NOT USE ON THE JOB

Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-25
November 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 25

PARALLEL RESONANCE

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

Title	Page
Overview	i
List of Resources	i
Adjunct Guide	1
Laboratory Exercise 25-1	4
Module Self-Check	6
Answers	8

OVERVIEW

1. SCOPE: This module is a continuation in your study of the parallel RCL circuit. If the frequency applied to a parallel RCL circuit is varied, the inductive reactance can be made equal to the capacitive reactance. When this occurs, we have resonance. This module discusses the conditions that exist when the parallel circuit is resonant. Resonant circuits are widely used in radio, radar, and telephone circuits. Practical training to determine bandwidth, bandpass, and resonant frequency completes the module.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given the response curves of parallel RCL circuits, compare the magnitude of current flow at resonance and off resonance.

b. Given a parallel RCL circuit and formulas, determine the effects on current, impedance, and phase angle by individually varying:

(1) Frequency.
(2) Resistance.
(3) Capacitance.
(4) Inductance.

c. Given component values of a parallel RCL circuit, calculate the resonant frequency.

d. Using a parallel RCL circuit connected on a trainer, signal generator, and multimeter, determine the bandwidth, bandpass, half power points, and resonant frequency.

LIST OF RESOURCES

To satisfy the objectives of this module you may choose, according to your training, experience, and preferences, any or all of the following.

Supersedes KEP-GP-25, 1 May 1975, which may be used until stock is exhausted.

READING MATERIALS:

Digest

Adjunct Guide with Student Text III

AUDIOVISUALS:

TVK30-264, Parallel RCL Circuits (Resonance)

LABORATORY EXERCISE:

25-1, Parallel Resonance

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK. IF NOT, SELECT ONE OF THE RESOURCES AND BEGIN STUDY.

CONSULT YOUR INSTRUCTOR IF YOU NEED ASSISTANCE.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced material as directed.

Return to this guide and answer the questions.

Confirm your answers at the back of this guidance package.

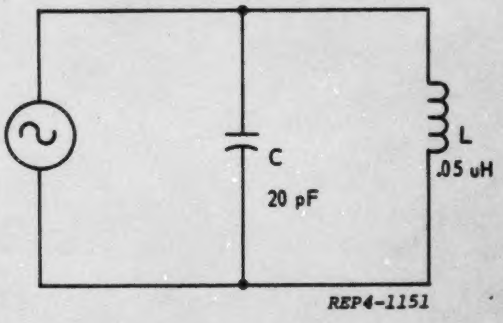
If you experience any difficulty, contact your instructor.

Begin the program.

A. Turn to Student Text Volume III and read paragraphs 6-1 through 6-9. Return to this page and answer the following questions.

1. Solve for the resonant frequency.

f_r = ______________________



2. Solve for the resonant frequency when L is .6 mH and C is 10 pF.

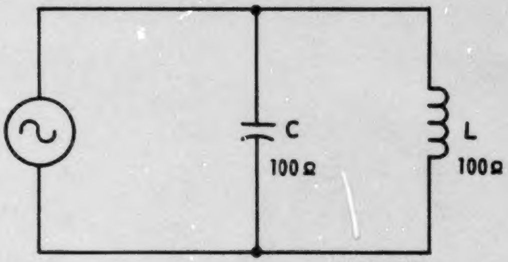
f_r = ______________________

3. In a parallel resonant circuit, what is the phase relationship between E_C and E_L?

4 What is the definition of parallel resonance?

5. A parallel resonant circuit is operating below resonance. The applied frequency is increased. What happens to line current?

6. In the following circuit, if X_L is increased to 200 ohms, what happens to line current?



REP4-1152

CONFIRM YOUR ANSWERS.

B. Turn to Student Text Volume III and read paragraphs 6-10 through 6-24. Return to this page and answer the following questions.

1. What factors cause the small energy loss during the charging and discharging of the capacitor through the coil?

2. After the capacitor is fully discharged, the magnetic field built up around the coil will:

3. What term is applied to a wave that diminishes in amplitude as it loses energy?

CONFIRM YOUR ANSWERS.

C. Turn to Student Text Volume III and read paragraphs 6-25 through 6-34. Return to this page and answer the following questions.

1. Why is there minimum line current in a parallel resonant circuit at resonance?

2. If the line current is minimum at resonance, what can be deduced about impedance?

3. How does line current and the impedance of a parallel resonant circuit compare to a series resonant circuit?

CONFIRM YOUR ANSWERS.

D. Turn to Student Text Volume III and read paragraphs 7-1 through 7-8. Return to this page and answer the following questions.

1. At resonance, a parallel RCL circuit has:

   a. Maximum current in the line.
   b. Maximum impedance.
   c. The characteristics of an inductor.
   d. The characteristics of a capacitor.

2. At resonance, a series RCL circuit has:

   a. Minimum current in the line.
   b. Minimum impedance.
   c. The characteristics of an inductor.
   d. The characteristics of a capacitor.

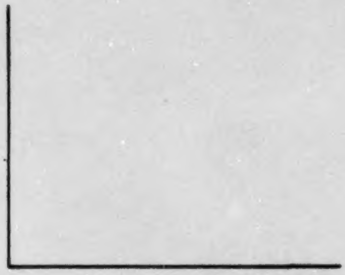
3. When frequencies BELOW the resonant frequency are applied, a parallel RCL circuit will act:

a. Inductively.

b. Capacitively.

c. Resistively.

5. Draw a current response curve to show the condition of current below, at, and above resonance for a parallel RCL circuit.



REP4-1153

6. Compare the action of a series RCL circuit and a parallel RCL circuit at a frequency below the point of resonance.

	SERIES RCL	PARALLEL RCL
a.	Acts capacitively	Acts capacitively
b.	Acts capacitively	Acts inductively
c.	Acts inductively	Acts capacitively
d.	Acts inductively	Acts inductively

CONFIRM YOUR ANSWERS.

E. Turn to Student Text Volume III and read paragraphs 7-9 through 7-27. Return to this page and answer the following questions.

1. The bandpass of a tank circuit can be increased by:

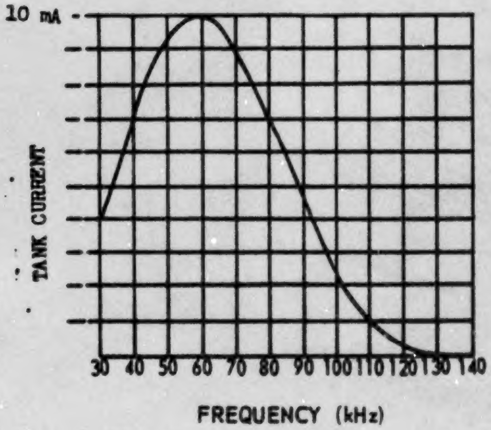
a. Increase frequency.

b. Decrease the inductance.

c. Increase the applied voltage.

d. Increase the resistance in the tank.

2. What is the current at the half power points, bandwidth, bandpass, and resonant frequency of the tank circuit represented by this graph?



REP4-1156

a. Half power point ________________

b. Bandwidth ________________

c. Bandpass ________________

d. Resonant frequency ________________

3. With the circuit at resonance, solve for:

a. I_C = ________

b. I_L = ________

c. Z = ________

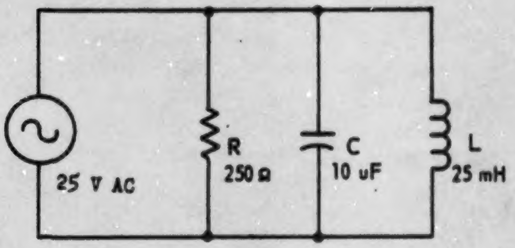
d. I_{tank} = ________

e. I_{line} = ________

f. BW = ________

g. f_r = ________

h. Bandpass = ____



REP4-1157

CONFIRM YOUR ANSWERS.

F. Turn to Laboratory Exercise 25-1 in which you will use a multimeter and a parallel RCL circuit to determine the resonant frequency, bandwidth, bandpass, and half power points. Return and continue with this program upon completion of the exercise.

G. Turn to Student Text Volume III and read paragraphs 8-1 through 8-28. Return to this page and answer the following questions.

1. If a parallel RCL circuit is below resonance, it can be brought into resonance by:

   a. Increasing R.

   b. Decreasing C.

   c. Increasing L.

   d. Decreasing f.

2. If the inductor opens in a parallel resonant RCL circuit, total current will:

   a. Increase.

   b. Decrease.

   c. Remain the same.

   d. Unable to determine what current will do without circuit values.

3. A parallel tank circuit is operating at its upper half power point. Increasing capacitance will cause the circuit to act:

   a. More capacitively.

   b. Less capacitively.

   c. More inductively.

   d. Less inductively.

4. If the applied frequency to a parallel resonant RCL circuit is increased, the total current will:

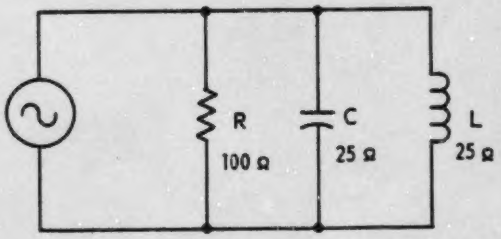
   a. Decrease and lag the applied voltage.

   b. Decrease and lead the applied voltage.

   c. Increase and lag the applied voltage.

   d. Increase and lead the applied voltage.

5. Using the resonant circuit shown, fill in the chart to indicate the effects of the parameter changes on the listed values.



	X_C	X_L	I_C	I_L	I_{LINE}	Z	θ
FREQ ↑							
CAP ↓							
IND ↑							
RES ↑							
E_a ↑							

CONFIRM YOUR ANSWERS.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

LABORATORY EXERCISE 25-1

OBJECTIVE:

Using a multimeter, formulas, and a parallel RCL circuit, determine the resonant frequency, bandwidth, bandpass, and half power points.

EQUIPMENT:

1. Multimeter, ME-70A/PSM-6
2. Sine Square Wave Generator, 4864
3. AC Inductor and Capacitor Trainer, 5967

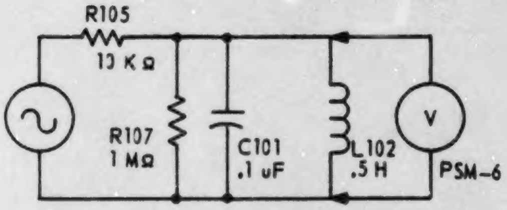
REFERENCES:

1. Student Handout, KEP-108
2. Student Text, Volume III, Chapters 6, 7, and 8

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

1. Construct the circuit in this diagram.



REP4-1160

2. Set PSM-6 on the 10 VAC range.

3. Adjust the sine wave output of the generator to maximum.

4. Set the generator FREQ MULTIPLIER to 10 and the FREQUENCY (Hz) dial to Midscale.

5. While observing the PSM-6, rotate the FREQUENCY dial until the voltage reading peaks.

NOTE: This is the resonant frequency of the circuit (f_r).

6. Record f_r. ______ Hz

7. Reduce the signal generator output voltage to 6V. (THE CIRCUIT IS STILL AT RESONANCE.)

8. If 6V is the maximum voltage, what is the voltage at the half power point?

______ VAC

CONFIRM YOUR ANSWERS.

---

9. While observing the voltmeter, DECREASE the frequency of the signal generator until the lower half power point is reached.

10. Record this as the lower frequency half power point (f_{lo}).

f_{lo} = ______________________

11. Reset the signal generator to the resonant frequency.

12. To find the upper frequency half power point, INCREASE the frequency until the voltmeter again reads the voltage calculated in step 8.

13. Record this as the upper frequency half power point (f_{hi}).

f_{hi} = __________ Hz

14. What is the bandpass and bandwidth of the circuit?

   a. Bandpass is _____ to _____ Hz.

   b. Bandwidth is _____ Hz.

CONFIRM YOUR ANSWERS.

CONSULT YOUR INSTRUCTOR FOR THE PROGRESS CHECK.

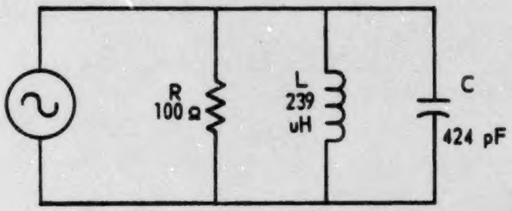
YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

1. What is the definition of parallel resonance?

2. Solve for the resonant frequency.

f_r = ______________________



REP4-1161

3. A parallel RCL circuit is operating above resonance. Is the inductive or the capacitive current greater?

4. A parallel RCL circuit is operating below resonance. If the applied frequency is decreased, what happens to line current?

5. The circuit in problem 2 is operating below resonance. Identify the following statements as true or false.

   a. I_R leads I_t.

   b. X_C is larger than X_L.

   c. I_L is smaller than I_C.

   d. The circuit will act capacitively.

6. The circuit in problem 2 is operating below resonance. For an increase in the applied frequency (identify as true or false):

   a. The phase angle will decrease.

   b. X_L will increase and X_C will decrease.

   c. I_L will decrease and I_C will increase.

   d. I_t will increase.

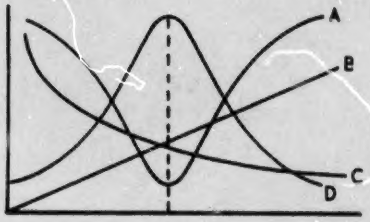
7. Identify the curve representing line current below, at, and above resonance for a parallel circuit.

   a. Curve A

   b. Curve B

   c. Curve C

   d. Curve D



REP4-1140

8. A parallel tank circuit is operating at the upper half power point. Increasing inductance will cause the circuit to act:

   a. More capacitively.

   b. Less capacitively.

   c. More inductively.

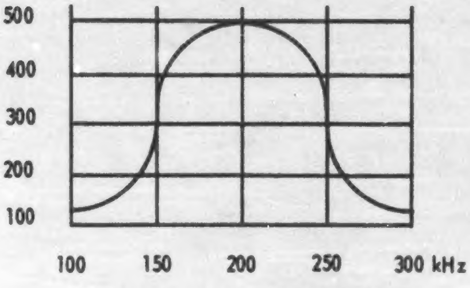
   d. Less inductively.

9. Determine the bandwidth, bandpass, and resonant frequency from the graph.

BW = ____________________

BP = ____________________

f_r = ____________________



REP4-1165

10. What is the characteristic of line impedance for a parallel RCL circuit at the resonant frequency?

a. Minimum

b. Maximum

c. Cannot be determined

11. If the capacitor opens in a parallel resonant RCL circuit, line current will:

a. Increase.

b. Decrease.

c. Remain the same.

d. Cannot be determined.

12. If the capacitor opens in a parallel resonant circuit, the phase angle between line voltage and line current:

a. Remains the same.

b. Increases.

c. Decreases.

d. Cannot be determined.

13. At resonance, a parallel resonant circuit acts:

a. Capacitively.

b. Inductively.

c. Resistively.

CONFIRM YOUR ANSWERS.

ANSWERS TO A:

1. 159 MHz

2. 2 MHz

3. In phase

4. The point where $I_C = I_L$

5. It decreases until it reaches minimum at the point of resonance.

6. It would increase.

If you missed ANY of the questions, review the material before you continue.

ANSWERS TO B:

1. The DC resistance of the coil and the connecting wires

2. The magnetic field around the coil will collapse. This causes the capacitor to be charged in the opposite direction.

3. A dampened wave

If you missed ANY of the questions, review the material before you continue.

ANSWERS TO C:

1. At resonance, the tank circuit offers maximum impedance to the generator. Tank circuit voltage is a little smaller than the generator voltage, due to the small energy loss in the resistance of the tank circuit; therefore, a small current will flow in the line.

2. Impedance is maximum.

3. Opposite. Parallel resonance, I_{line} is minimum and Z is maximum. Series resonance, I_{line} is maximum and Z is minimum.

If you missed ANY questions, review the material before you continue.

ANSWERS TO D:

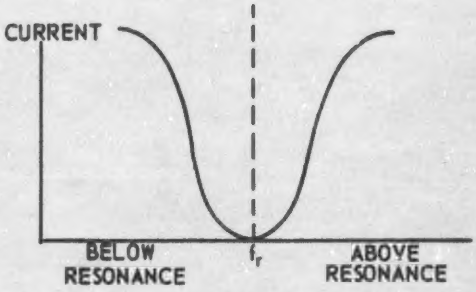
1. b

2. b

3. a

4. b

5.



REP4-1154

6. b

If you missed ANY questions, review the material before you continue.

ANSWERS TO E:

1. d

2. a. 7 mA
   b. 40 kHz
   c. 40 kHz to 80 kHz
   d. 60 kHz

3. a. .5 A
   b. .5 A
   c. 250 ohms
   d. .5 A
   e. .1 A
   f. 63.6 Hz
   g. 318 Hz
   h. 286.2 Hz to 349.8 Hz

If you missed ANY questions, review the material before you continue.

ANSWERS TO G:

1. c

2. a

3. a

4. d

5.

	X_C	X_L	I_C	I_L	I_{LINE}	Z	•
FREQ ↑	↓	↑	↑	↓	↑	↓	↑
CAP ↓	↑	→	↓	→	↑	↓	↑
IND ↑	→	↑	→	↓	↑	↓	↑
RES ↑	→	→	→	→	↓	↑	→
Ea ↑	→	→	↑	↑	↑	→	→

If you missed ANY questions, review the material before you continue.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

ANSWERS TO LAB EXERCISE:

6. f_r should be around 660 Hz. Verify with instructor.

8. 4.242 VAC

10. Verify with instructor.

13. Verify with instructor.

14. a. Bandpass is f_{lo} to f_{hi}. (For example, 530 Hz to 840 Hz.)
    b. Bandwidth = $f_{hi} - f_{lo}$. (For example, 100 Hz.)

Have your instructor verify your answers.

If you missed ANY questions, review the material before you continue.

CONSULT YOUR INSTRUCTOR FOR THE PROGRESS CHECK.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

ANSWERS TO MODULE SELF-CHECK:

1. That frequency where $I_C = I_L$.

2. 500 kHz

3. Capacitive current

4. Line current increases

5. a. True
   b. True
   c. True
   d. False

6. a. True
   b. True
   c. True
   d. False

7. a

8. a

9. BW = 100 kHz
   BP = 150 kHz to 250 kHz
   f_r = 200 kHz

10. b

11. a

12. b

13. c

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

318

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-26

Technical Training

Electronic Principles (Modular Self-Paced)

Module 26

TIME CONSTANTS

1 August 1975

AIR TRAINING COMMAND

7-7

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KEP-GP-26
1 August 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 26

TIME CONSTANTS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

Title	Page
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List of Resources	1
Adjunct Guide	1
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Module Self-Check	11
Answers	14

OVERVIEW

1. SCOPE: The function of many electronic circuits is to produce a variety of nonsinusoidal waveforms. These include square waves, sawtooth waves, trapezoidal waves, and peaked waves. These circuits depend upon the transient behavior of RC or RL circuits to changes in voltage or current. This module discusses this behavior. The time required for a circuit to respond to a change in voltage or current is expressed as a time constant. The time constant is determined solely by the values of the components. You will determine circuit response by using a universal time constant chart. Practical training is provided on time constant circuits.

2. OBJECTIVES: Upon completion of this module, you should be able to satisfy the following objectives:

a. Given a DC series RC circuit, specified time, component values, and a Universal Time Constant chart, determine:

(1) The percent of charge on a capacitor.

(2) The percent of discharge of a capacitor.

b. Given a DC series RL circuit, specified time, component values, and a Universal Time Constant chart, determine:

(1) The percent of current buildup.

(2) The percent of current decay.

c. Given series RC and RL circuits with component values and formulas, compute the time constant for each.

d. Given waveshapes of long, medium, and short time constants of RC and RL circuits, identify E_C, E_R, and E_L with the correct waveform.

Supersedes KEP-GP-26, 1 July 1974. All previous editions are obsolete.

e. Given a trainer containing series RC or RL networks, oscilloscope, specified square wave frequency and voltage, identify the output wave as either differentiated or integrated.

LIST OF RESOURCES

To satisfy the objectives of this module you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text

AUDIOVISUALS:

TVK 30-851, RC Transients

TVK 30-852, RL Transients and Wave Shaping

LABORATORY EXERCISE:

26-1, Time Constants

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

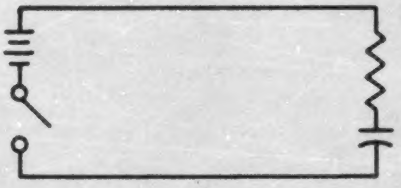
Check your answers against the answers at the back of this guidance package.

If you experience any difficulty, contact your instructor.

Begin the program.

A. Turn to the Student Text, Volume III, and read paragraphs 9-1 through 9-8. Return to this page and answer the following questions.

1. In the RC circuit shown, what two factors govern the time required for the capacitor to become fully charged?



REP4-1195

a. Size of the resistor and amplitude of E_a.

b. Size of the capacitor and amplitude of E_a.

c. Size of the capacitor and size of the resistor.

d. Transient response and size of the switch.

2. What term is used to describe the time it takes for a voltage or current to change from one steady state to another steady state? ______________________________

3. What term is used to describe the product of RC? ______________________

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDANCE PACKAGE.

B. Turn to the Student Text, Volume III, and read paragraphs 9-9 through 9-19. Return to this page and answer the following questions.

1. In one time constant a capacitor will charge to ________ percent of the applied voltage.

2. How many time constants are needed for a capacitor to become fully charged?

a. Two

b. Three

c. Four

d. Five

3. What factor determines the rate of charge in an RC circuit?

a. The resistor

b. The applied voltage

c. The capacitor

4. How many time constants are needed for a capacitor to lose 98 percent of its original charge?

a. Two

b. Three

c. Four

d. Five

5. At the end of two time constants, the capacitor in an RC circuit has discharged _____ percent. The charge remaining on the capacitor is _____ percent of the initial charge.

a. 86.3 13.7

b. 13.7 86.3

c. 86.3 86.3

d. 13.7 13.7

6. After 1.5 time constants, the voltage across the resistor in an RC circuit has decreased by _____ percent.

a. 22.5

b. 77.5

c. 25

d. 75

7. Using the Universal Time Constant Chart, determine the percent of E_a on the capacitor at the end of the following time constants.

	On Charge	On Discharge
a. .3 TC		
b. .9 TC		
c. 1.2 TC		
d. 2.4 TC		
e. 3 TC		

8. Using the Universal Time Constant Chart determine the number of time constants when the following percentages of the applied voltage are across the resistor during capacitor charge.

a. 90 percent _________ TC

b. 50 percent _________ TC

c. 30 percent _________ TC

d. 5 percent _________ TC

e. 2 percent _________ TC

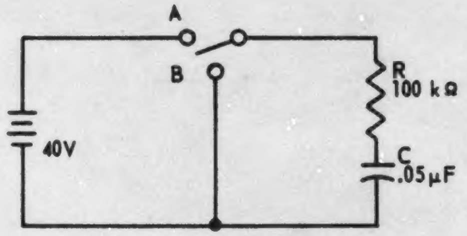
CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDANCE PACKAGE.

C. Turn to the Student Text, Volume III, and read paragraphs 9-20 through 9-33. Return to this page and answer the following questions.

1. Find the voltage across the capacitor and the resistor 10,000 microseconds after the switch is placed in position A.

E_C = ______________________

E_R = ______________________



REP4-1196

2. Reference the circuit in question one. If the capacitor was fully charged, what is the voltage across the resistor, and the current in the circuit, 15,000 microseconds after the switch is placed in position B.

E_R = ______________________

I = ______________________

3. Reference the circuit in question one. What is the number of time constants required for E_C to reach 18 volts after the switch is placed in position A?

#TC = ______________________

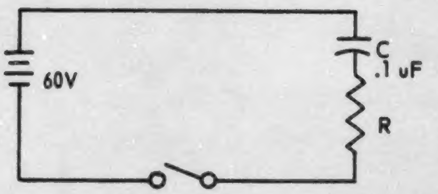
4. A capacitor in an RC circuit is charged to 100 volts and then starts to discharge. At the end of three time constants what is the voltage across the capacitor and what is the voltage across the resistor?

E_C = ______________________

E_R = ______________________

5. If C charges to 46.5 volts 570 microseconds after the switch is closed, R must be what value?

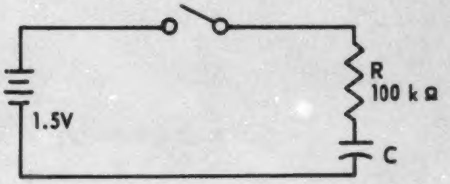
R = ______________________



REP4-1198

6. If C charges to 1.425 volts 2295 microseconds after the switch is closed, what is the value of C?

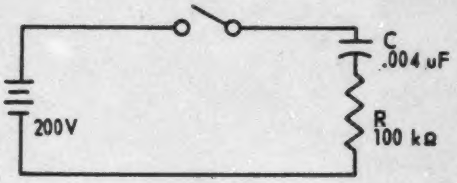
C = ______________________



REP4-1199

7. Eighty microseconds after the switch is closed, the current in the following circuit will be what value?

I = ______________________

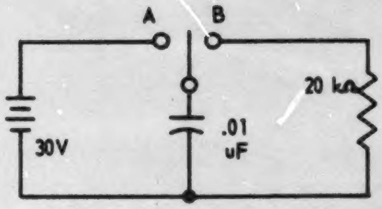


REP4-1200

8. In the following circuit, C has been charged to 30 volts with the switch in position A. Eighty microseconds after the switch is thrown to position B, E_C will be what value? What will the circuit current be?

E_C = ______________________

I = ______________________



REP4-1201

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDANCE PACKAGE.

D. Turn to the Student Text, Volume III, and read paragraphs 9-34 through 9-45. Return to this page and answer the following questions.

1. In an RL circuit, what two factors control the transient response of the circuit?

   a. Inductance and voltage

   b. Resistance and current

   c. Voltage and current

   d. Resistance and inductance

2. In an RL circuit, what is the relationship between time and inductance?

   a. Directly proportional

   b. Inversely proportional

3. On the Universal Time Constant Chart for LR circuits, curve A shows what two things on buildup?

   a. E_R and E_L

   b. E_L and I

   c. E_R and I

4. After 1.6 time constants, inductor current would have built up to _____ percent of its final value.

   a. 20

   b. 30

   c. 70

   d. 80

5. After three time constants, inductor current would have decayed by _____ percent. What percent of the initial current would still be flowing? _____ percent

a.	5	95
b.	25	75
c.	75	25
d.	95	5

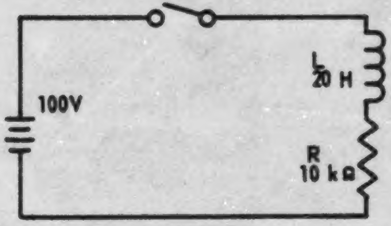
CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDANCE PACKAGE.

E. Turn to the Student Text, Volume III, and read paragraphs 9-46 through 9-53. Return to this page and answer the following questions.

1. Find the percent of current buildup and the voltage across the coil after the switch has been closed for 4000 microseconds.

   percent of I = ____________________

   E_L = ____________________



REP4-1302

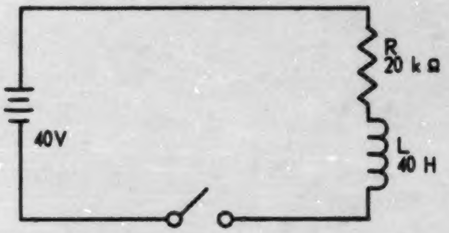
2. Using the circuit in problem one, solve for the current flow at the end of 2000 microseconds.

   I = ____________________

3. Solve for the voltage across the coil, and the circuit current, 1400 microseconds after the switch is closed.

E_L = ____________________

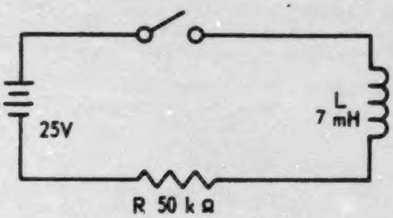
I = ____________________



REP4-1203

4. What will the current be 0.084 microsecond after the switch is closed?

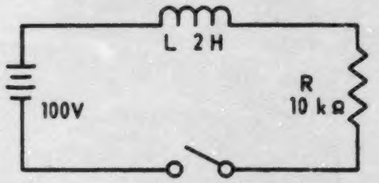
I = ____________________



REP4-1204

5. Solve for current flow 200 microseconds after the switch is closed.

I = ____________________



REP4-1205

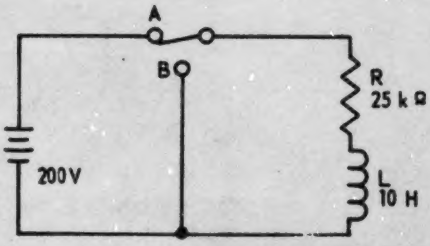
6. The switch is placed into position A until a field is completely built up around the coil, then placed in position B. The voltage across the resistor, 600 microseconds after the switch is placed in position B will decrease by what percent?

a. 23 percent

b. 49 percent

c. 51 percent

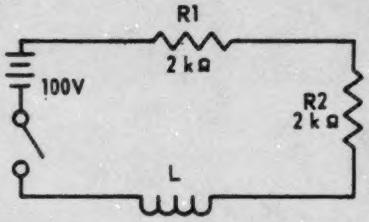
d. 77 percent



REP4-1209

7. Six microseconds after the switch is closed the voltage across each resistor is 28 volts. Solve for the value of L.

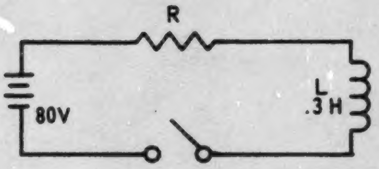
L = ____________________



REP4-1207

8. The voltage across R is 36 volts 200 microseconds after the switch is closed. What is the value of R?

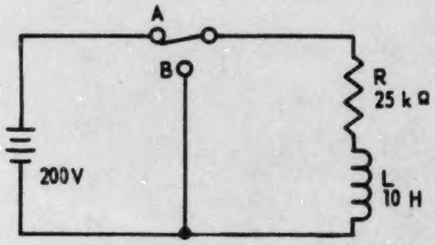
R = ____________________



REP4-1208

9. The switch is placed into position A until a field is completely built up around the coil then placed in position B. What is the voltage across the resistor 600 microseconds after the switch is placed in position B?

E_R = ______________________________



REP4-1209

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDANCE PACKAGE.

F. Turn to the Student Text, Volume III, and read paragraphs 9-54 through 9-69. Return to this page and answer the following questions.

1. The output frequency of a symmetrical square wave generator is 5000 Hz. What is the time of one alternation?

t = ______________________________

2. The time of one alternation of an unknown symmetrical square wave is 40 microseconds. What is the frequency?

f = ______________________________

3. What determines whether a time constant is long, medium, or short? ______________

____

____

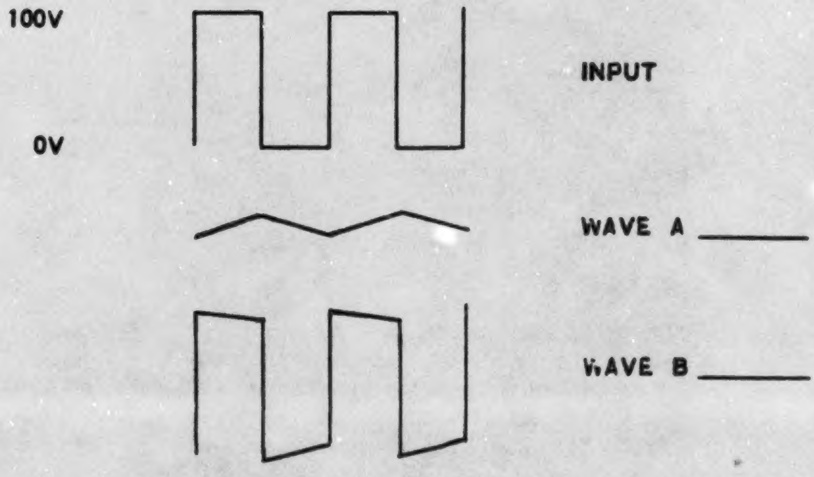
____

____

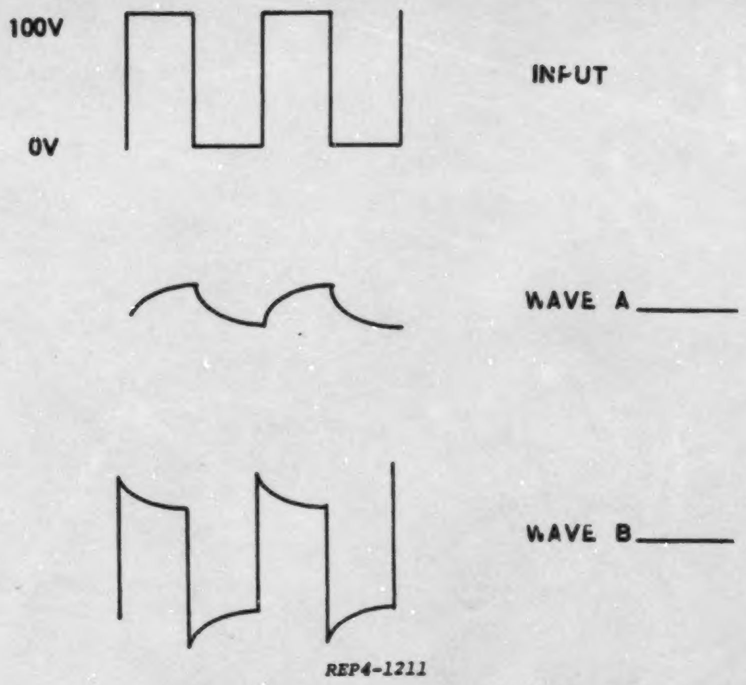
____

4. Identify the following waveforms for the resistor voltage and capacitor voltage in an RC circuit. Also specify whether it is a long, medium, or short time constant.

______________ **time constant**



REP4-1210

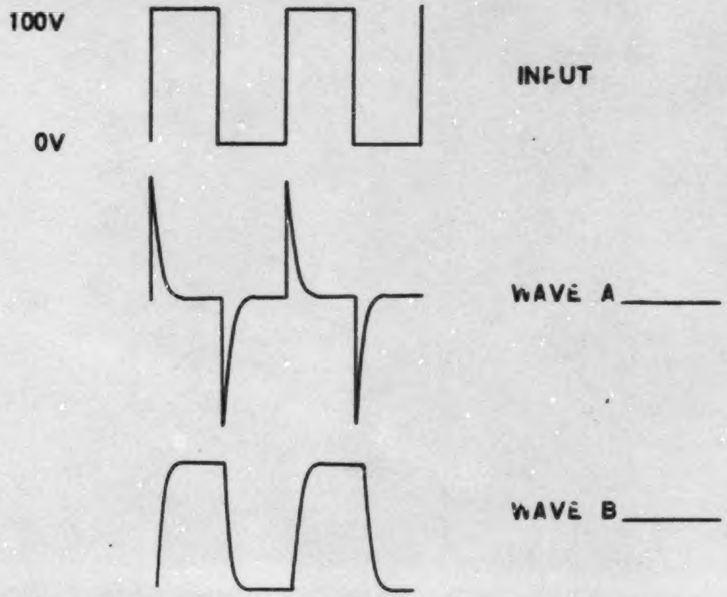

100V
0V
INPUT
WAVE A ______
WAVE B ______
REP4-1211

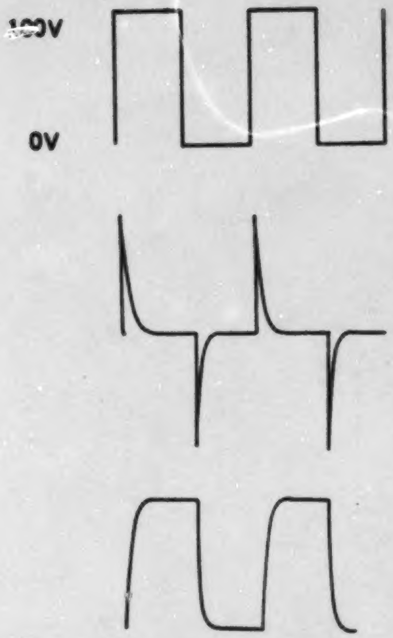
5. Identify the waveforms shown above for the resistor voltage and capacitor voltage in an RC circuit. Also identify whether it is a long, medium, or short time constant.

______________ time constant

6. Identify the following waveforms for the resistor voltage and capacitor voltage in an RC circuit. Also identify whether it is a long, medium, or short time constant.

______________ time constant


100V
0V
INPUT
WAVE A ______
WAVE B ______



INPUT

WAVE A ________

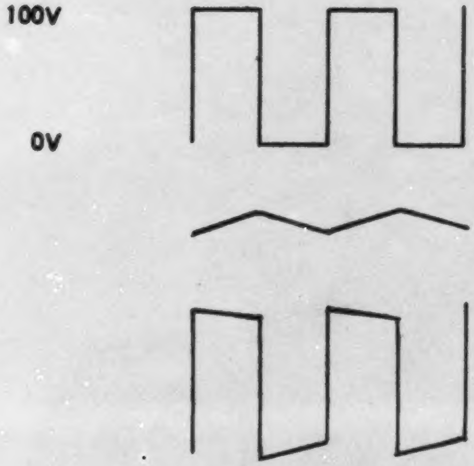
WAVE B ________

7. Identify the waveforms shown above for the resistor voltage and the inductor voltage in an RL circuit. Also identify whether it is a long, medium, or short time constant.

______________ time constant

8. Identify the following waveforms for the resistor voltage and inductor voltage in an RL circuit. Also identify whether it is a long, medium, or short time constant.

______________ time constant

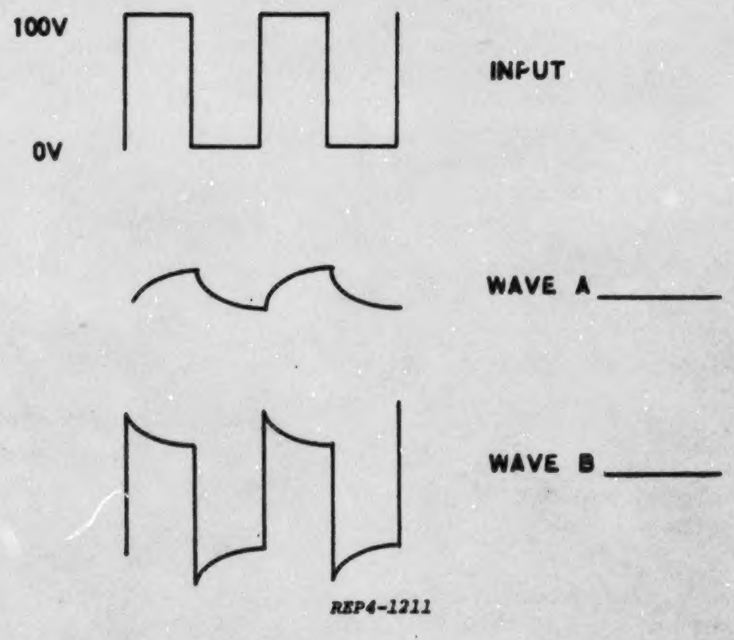


INPUT

WAVE A ________

WAVE B ________

REP4-1210



REP4-1211

9. Identify the waveforms shown above for the resistor voltage and the inductor voltage in an RL circuit. Also identify whether it is a long, medium, or short time constant.

________ time constant

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDANCE PACKAGE.

G. Turn to the Student Text, Volume III, and read paragraphs 9-70 through 9-92. Return to this page and answer the following questions.

1. Define a differentiation circuit. ________

____

____

2. What portion of an RC or RL circuit is used to obtain a differentiated output? Also, indicate what type of time constant is used.

____

____

____

3. Define an integrating circuit. ________

____

____

____

____

____

4. What portion of an RC or RL circuit is used to obtain an integrated output? Also, indicate what type time constant is used.

____

____

____

____

____

____

____

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDANCE PACKAGE.

H. Turn to Laboratory Exercise 26-1 in which you will use the scope to identify output waveforms of an RC or RL circuit as either integrated or differentiated.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

LABORATORY EXERCISE 26-1

OBJECTIVES:

1. Given a circuit diagram, a trainer, and an input square wave of a specified frequency and amplitude, connect the circuit on the trainer.
2. Given an oscilloscope, identify the output waveform of an RC or an RL circuit as either integrated or differentiated.

EQUIPMENT:

1. Oscilloscope, AN/USM-398
2. AC Inductor and Capacitor Trainer, 5217
3. Sine Square Wave Generator, 4864

REFERENCES:

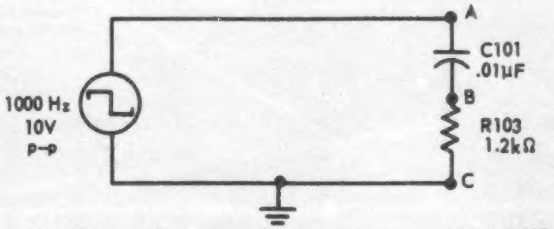
1. Student Handout, KEP-108
2. Student Text, Volume III, Chapter 9

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

USM-398	Turn ON
Intensity	Fully CCW
CH1	Mid
CH2	OFF
V/CM	5
AC-GND-DC	AC
Sep-CH1 & CH2	Sep
AC-ACF-DC	AC
CHOP-ALT	ALT
Hor Pos	Mid
Time/CM	.2 ms
Trig Select	CH1+
Level	AUTO

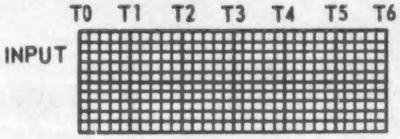
1. Connect this circuit.



REP4-2601

2. Display on the oscilloscope three cycles of the generator voltage. Keep the amplitude at 2 cm (CH1 to point A and ground to point C).

3. Draw this square wave input to the circuit. Let T0 to T2 be the time for one cycle.



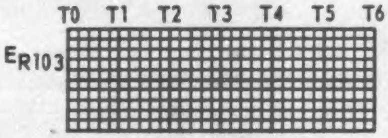
REP4-1215

4. Display the voltage waveform across R103 and draw E_{R103} (CH1 to point B and ground to point C). Adjust amplitude to 2 cm.

5. This waveform is:

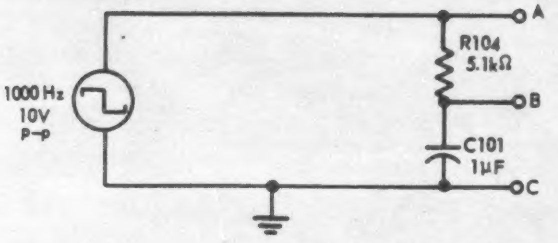
a. Integrated.

b. Differentiated.



REP4-1216

6. Construct this circuit and display the capacitor waveform on the scope. Draw the waveform for C101 (CH1 to point B and ground to point C). Adjust amplitude to 2 cm.

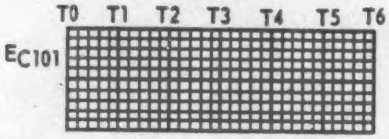

A
R104
5.1kΩ
B
1000 Hz
10V
P-P
C101
1μF
C

REP4-2602

7. This waveform is:

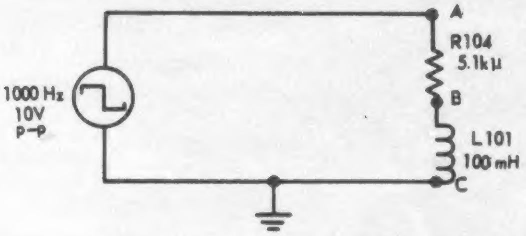
a. Differentiated.

b. Integrated.


T0
T1
T2
T3
T4
T5
T6
EC101

REP4-1217

8. Replace C101 with coil L101.


A
R104
5.1kμ
B
1000 Hz
10V
P-P
L101
100 mH
C

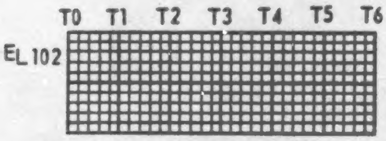
REP4-2603

9. Display E_{L101} on the scope. Set amplitude to 2 cm and draw the waveform E_{L101} (CH1 to point B and ground to point C).

10. This waveform is:

a. Differentiated.

b. Integrated.


T0
T1
T2
T3
T4
T5
T6
EL 102

REP4-1218

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDANCE PACKAGE.

CONSULT YOUR INSTRUCTOR FOR THE PROGRESS CHECK.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

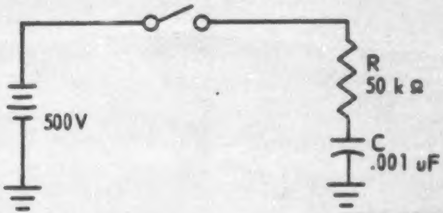
1. Solve for percent of charge, E_C, E_R, and I, 25 microseconds after the switch is closed.

percent of charge = ____________

E_C = ____________

E_R = ____________

I = ____________


500V
R
50 kΩ
C
.001 uF

REP4-1220

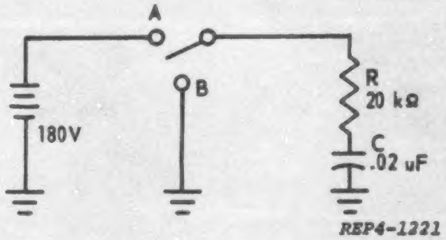
2. Solve for percent of charge, E_C, E_R, and I, 1200 microseconds after switch is closed to point A.

percent of charge = ____________

E_C = ____________

E_R = ____________

I = ____________


A
B
180V
R
20 kΩ
C
.02 uF

REP4-1221

3. Using the circuit in problem 2, the capacitor has charged to 180 volts. What is percent of discharge, percent of charge remaining, E_C, E_R, and I, 800 microseconds after the switch is placed in position B?

percent of discharge = ________________

percent remaining = ________________

E_C = ______________________________

E_R = ______________________________

I = ______________________________

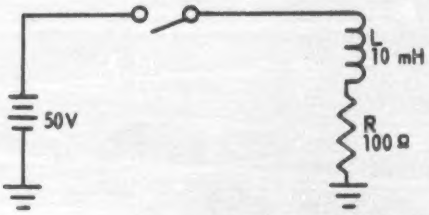
4. Solve for percent of current buildup, E_L, E_R, and I, 200 microseconds after the switch is closed.

percent of buildup = ________________

E_L = ______________________________

E_R = ______________________________

I = ______________________________

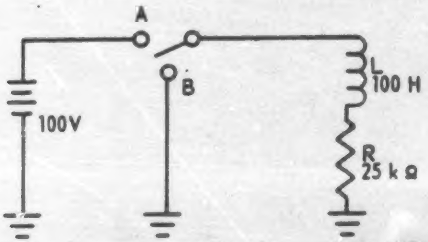


REP4-1222

5. The switch is placed in position A until the field is completely built up. Solve for percent of current decay and current, 1200 microseconds after the switch is placed in position B.

percent of decay = ________________

current = ________________________



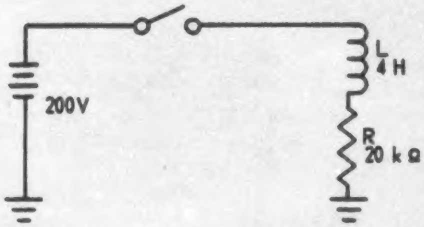
REP4-1223

6. Solve for E_L, E_R, and I, 400 microseconds after the switch is closed.

E_L = ______________________________

E_R = ______________________________

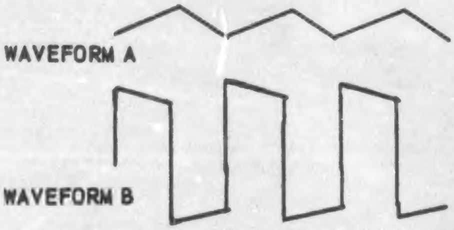
I = ______________________________

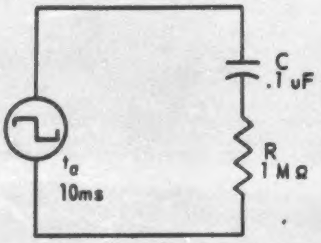


REP4-1224

7. Identify the following circuit as having a long, medium, or short time constant. Label the waveforms as E_R or E_C.

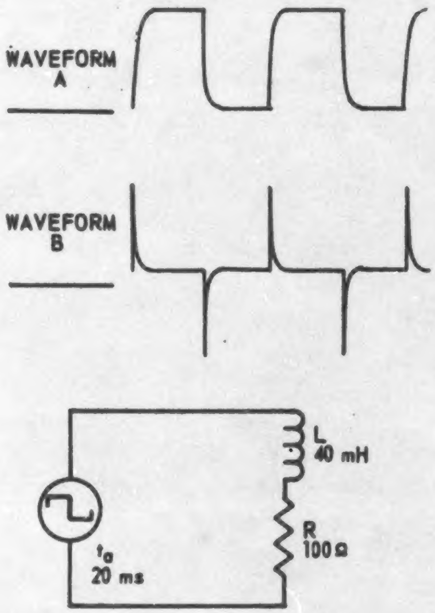
________________ time constant





8. Identify the circuit shown below as having a long, medium, or short time constant. Label E_L and E_R.

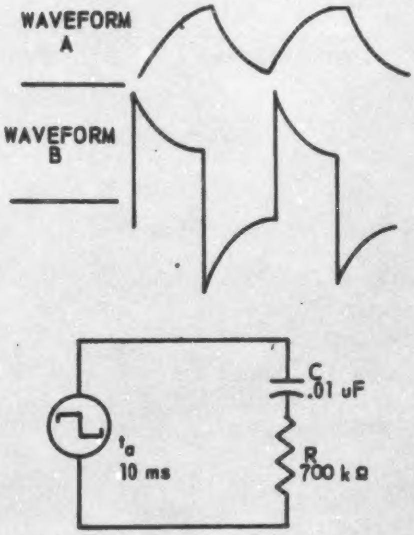
______________ time constant


WAVEFORM A
WAVEFORM B
L
40 mH
R
100 Ω
t_a
20 ms

REP4-1226

9. Identify the following circuit as having a long, medium, or short time constant. Label the waveforms as E_C or E_R.

______________ time constant


WAVEFORM A
WAVEFORM B
C
.01 uF
R
700 k Ω
t_a
10 ms

REP4-1227

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDANCE PACKAGE.

ANSWERS TO A:

1. c
2. Transient interval
3. A time constant

If you missed ANY questions, review the material before you continue.

ANSWERS TO B:

1. 63 percent
2. d
3. b
4. c
5. a
6. b
7. a. 27 percent, 73 percent
   b. 60 percent, 40 percent
   c. 70 percent, 30 percent
   d. 91 percent, 9 percent
   e. 95 percent, 5 percent
8. a. 0.1 TC
   b. 0.7 TC
   c. 1.2 TC
   d. 3 TC
   e. 4 TC

If you missed ANY questions, review the material before you continue.

ANSWERS TO C:

1. $E_C = 34.52V$
   $E_R = 5.48V$
2. $E_R = 2$ volts, I = 20 microamps
3. #TC = 0.6 TC
4. $E_C = 5V$, $E_R = 5V$
5. R = 3800 ohms
6. C = 7650 picofarads
7. I = 1.6 mA
8. $E_C = 20.1V$, I = 1 mA

If you missed ANY answers, review the referenced material before you continue.

ANSWERS TO D:

1. d
2. a
3. c
4. d
5. d

If you missed ANY answers, review the referenced material before you continue.

ANSWERS TO E:

1. percent of I = 86 percent
   $E_L = 14$ volts
2. I = 6.3 mA
3. $E_L = 20$ volts
   I = 1 mA
4. 0.225 mA
5. I = 6.3 mA
6. d
7. L = 30 mH
8. R = 900 ohms
9. $E_R = 46$ volts

If you missed ANY questions, review the referenced material before you continue.

ANSWERS TO F:

1. 100 microseconds

2. 12.5 kHz

3. The time allowed or the time to which the time constant is being compared.

4. Long time constant; wave A = E_C; wave B = E_R

5. Medium time constant; wave A = E_C; wave B = E_R

6. Short time constant; wave A = E_R; wave B = E_C

7. Short time constant; wave A = E_L; wave B = E_R

8. Long time constant; wave A = E_R; wave B = E_L

9. Medium time constant; wave A = E_R; wave B = E_L

If you missed ANY questions, review the referenced material before you continue.

ANSWERS TO G:

1. Differentiating circuits produce an output voltage proportional to the rate of change of the input.

2. A short time constant is used and the output is taken across the resistor in an RC circuit or the inductor in an RL circuit.

3. An integrating circuit produces an output voltage that is proportional to the area under the input waveform.

4. A long time constant is used and the output is taken across the capacitor in an RC circuit and across the resistor in an RL circuit.

If you missed ANY questions, review the referenced material before you continue.

ANSWERS TO LAB EXERCISE:

5. b

7. b

10. a

If you missed ANY questions, review the reference material before you continue.

ANSWERS TO MODULE SELF-CHECK:

1. percent of charge = 40 percent
   E_C = 200V
   E_R = 300V
   I = 6 mA

2. percent of charge = 95 percent
   E_C = 171V
   E_R = 9V
   I = 0.45 mA

3. percent of discharge = 86 percent
   percent remaining = 14 percent
   E_C = 25.2V
   E_R = 25.2V
   I = 1.26 mA

4. percent of I buildup = 86 percent
   E_L = 7V
   E_R = 43V
   I = 0.43A

5. percent of I decay = 25 percent
   I = 3 mA

6. E_L = 28V
   E_R = 172V
   I = 8.6 mA

7. Long time constant
   E_C waveform A
   E_R waveform B

8. Short time constant
   E_R waveform A
   E_L waveform B

9. Medium time constant
   E_C waveform A
   E_R waveform B

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-27

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 27

FILTERS

April 1976

AIR TRAINING COMMAND

7-7

Designed For ATC Course Use

ATC Keesler 6-4618

DO NOT USE ON THE JOB

Electronic Principles LRC
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-27
April 1976

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 27

FILTERS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

	PAGE
Overview	1
List of Resources	1
Adjunct Guide	1
Module Self-Check	5

OVERVIEW

1. SCOPE: This module discusses filters. Filters use reactive components that pass or reject certain frequencies. Series and parallel circuits as well as RC and RL circuits are used as filters. This module discusses low-pass, high-pass, bandpass, and band reject filters. Filter circuits are used in radio receivers and transmitters, radar circuits, and navigation equipment.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. From a list of statements concerning filters, select the one that explains the low-pass filtering action of a:

(1) T-section.
(2) Pi-section.

b. From a list of statements concerning filters, select the one that explains high-pass filtering action of a:

(1) T-section.
(2) Pi-section.

c. From a list of statements concerning filters, select the one that explains the bandpass filtering action of a:

(1) parallel resonant circuit.
(2) series-parallel circuit.
(3) series resonant circuit.

d. From a list of statements concerning filters, select the one that explains the band-reject filtering action of a:

(1) parallel resonant circuit.
(2) series-parallel circuit.
(3) series resonant circuit.

Supersedes KEP-GP-27, 1 August 1975, which may be used.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text

AUDIO-VISUALS:

Television Lesson, Filters (A), TVK 30-305
Television Lesson, Filters (B), TVK 30-306

At this point, if you feel that through previous experience or training you are familiar with this subject, you may take the Module Self-Check. If not, select one of the resources and begin study.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers at the back of this Guidance Package.

If you experience any difficulty, contact your instructor.

Begin the program.

A. Turn to Student Text Volume III and read paragraphs 10-1 through 10-9. Return to this page and answer the following questions.

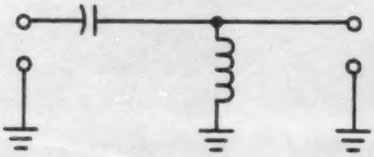
1. Define filter:

2. What impedance does a capacitor present to high frequencies? Low frequencies?

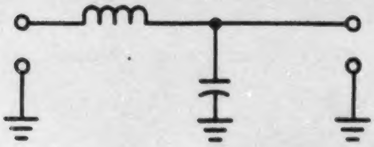
3. What impedances does an inductor present to high frequencies? Low frequencies?

4. Identify the following circuits as being a High Pass Filter, Low Pass Filter, Band Pass Filter, or Band Reject Filter.

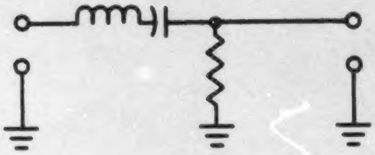
a.



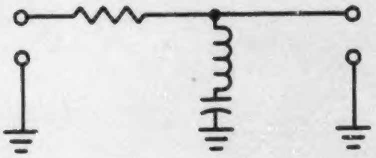
4. b. ____________________



c. ____________________



d. ____________________



REP4-1136

CONFIRM YOUR ANSWERS

B. Turn to Student Text Volume III and read paragraphs 10-10 through 10-22. Return to this page and answer the following questions.

1. Which of the following is a low-pass filter?

____ a. T section with series C and shunt L.

____ b. T section with shunt C and series L.

____ c. L section with series C and shunt L.

____ d. L section with shunt L and series R.

2. Draw a circuit diagram, using coils and capacitors, for a pi-type low-pass filter.

3. T and Pi-section low-pass filters use which of the following:

____ a. Series capacitors and shunt coils.

____ b. Series coils and shunt capacitors.

____ c. Series resistors and shunt coils.

____ d. Series capacitors and shunt resistors.

CONFIRM YOUR ANSWERS

C. Turn to Student Text Volume III and read paragraphs 10-23 through 10-29. Return to this page and answer the following questions.

1. Draw a circuit diagram, using coils and capacitors, for a T-section high-pass filter.

2. T and Pi-section high-pass filters use which of the following:

______ a. Series inductors and shunt capacitors.

______ b. Series resistors and shunt capacitors.

______ c. Series capacitors and shunt coils.

______ d. Series inductors and shunt resistors.

3. Draw a frequency response curve for a pi-section high-pass filter. (Show cutoff frequency.)

4. Which of the following is a high-pass filter?

______ a. T section with series L and shunt C.

______ b. T section with shunt L and series C.

______ c. L section with series L and shunt C.

______ d. L section with series R and shunt C.

CONFIRM YOUR ANSWERS

____

D. Turn to Student Text Volume III and read paragraphs 10-30 through 10-35. Return to this page and answer the following questions.

1. At resonance, is the circuit impedance maximum or minimum for a series resonant circuit?

____

2. At resonance, is the circuit impedance maximum or minimum for a parallel resonant circuit?

____

3. Draw a frequency rsponse curve for a bandpass filter. (Show cutoff frequencies.)

4. Which of the following describes an L-section bandpass filter?

______ a. Series resonant circuit in series with the output and a parallel resonant circuit in shunt with the output.

______ b. Parallel resonant circuit in series with the output and a series resonant circuit in shunt with the output.

______ c. Parallel resonant circuit in series and parallel with the output.

______ d. Series resonant circuit in series and parallel with the output.

5. An L-section resonant filter is used to pass a range of frequencies from 20 kHz to 30 kHz with a resonant frequency of 25 kHz. To what frequency is the series resonant circuit tuned and to what frequency is the parallel resonant tank tuned?

a. Series resonant circuit

____

b. Parallel resonant circuit

____

6. What is the main advantage of the T and pi-type resonant filters over the L section resonant filter?

____

____

____

____

CONFIRM YOUR ANSWERS.

E. Turn to Student Text Volume III and read paragraphs 10-36 through 10-39. Return to this page and answer the following questions:

1. Draw the frequency response curve for a band-reject filter. (Show cutoff frequencies.)

2. Which of the following describes an L-section band-reject filter?

_____ a. Series resonant circuit in series with the output and a parallel resonant circuit in shunt with the output.

_____ b. Parallel resonant circuit in series with the output and a series resonant circuit in shunt with the output.

_____ c. Parallel resonant circuit in series and parallel with the output.

_____ d. Series resonant circuit in series and parallel with the output.

3. What purpose does the parallel resonant tank serve in the Pi-type band-reject filter?

____

____

____

____

____

____

4. Recalling the characteristics of resonant circuits, what factor would govern the bandwidth of any type bandpass or band-reject filter?

____

____

____

____

____

CONFIRM YOUR ANSWERS

MODULE SELF-CHECK

Questions:

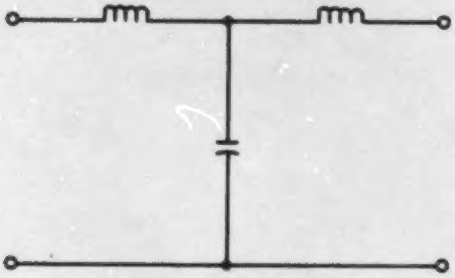
1. Identify the filter shown.

____ a. T-section low - pass

____ b. T-section high-pass

____ c. Pi-section low-pass

____ d. Pi-section high-pass



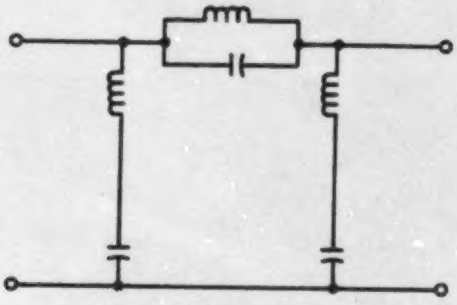
2. Identify the filter shown.

____ a. T-section band-reject

____ b. T-section bandpass

____ c. Pi-section band-reject

____ d. Pi-section bandpass



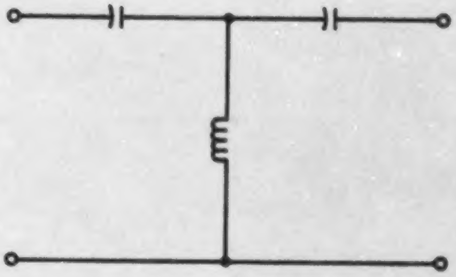
3. Identify the filter shown.

____ a. T-section low-pass

____ b. T-section high-pass

____ c. Pi-section low-pass

____ d. Pi-section high-pass



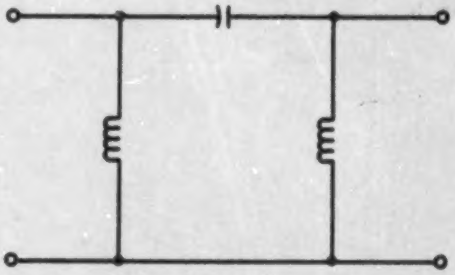
4. Identify the filter shown.

____ a. T-section low-pass

____ b. T-section high-pass

____ c. Pi-section low-pass

____ d. Pi-section high-pass



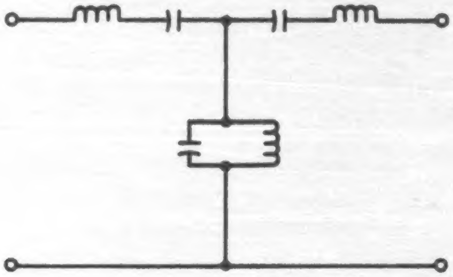
5. Identify the filter shown.

_____ a. T-section band-reject

_____ b. T-section bandpass

_____ c. Pi-section band-reject

_____ d. Pi-section bandpass



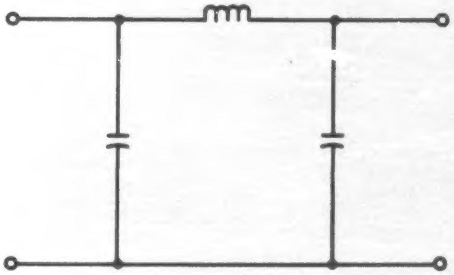
6. Identify the filter shown.

_____ a. T-section low-pass

_____ b. T-section high-pass

_____ c. Pi-section low-pass

_____ d. Pi-section high-pass



7. Which of the following are true (T) or false (F)?

_____ a. A T-section low-pass filter can be made into a high-pass filter by reversing the input and output connections.

_____ b. High-pass filters have capacitors in series with the output while low-pass filters have capacitors in parallel with the output.

_____ c. High pass filters have inductors in parallel with the output while low-pass filters have inductors in series with the output.

_____ d. A Pi-section band-reject filter has a series resonant circuit in series with the output and two parallel resonant circuits in parallel with the output.

_____ e. A T-section bandpass filter has two series resonant circuits in series with the output and a parallel resonant circuit in parallel with the output.

CONFIRM YOUR ANSWERS

ANSWERS TO A - ADJUNCT GUIDE

1. A filter is a number of impedances grouped together which are designed to pass a certain range of frequencies and to block another range of frequencies.

2. A capacitor presents very little opposition to high frequencies (a short) and a great deal of opposition to low frequencies (an open).

3. A coil or inductor presents a great deal of opposition to high frequencies (an open) and very little opposition to low frequencies (a short).

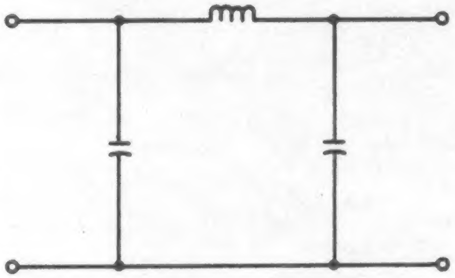
4. a. High pass filter
   b. Low pass filter
   c. Bandpass filter
   d. Band reject filter

If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. b

2.

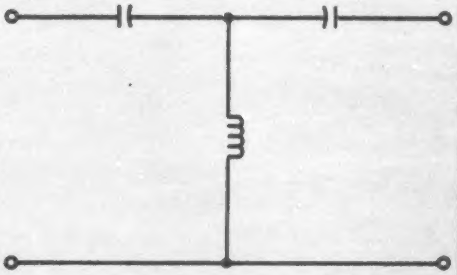


3. B

If you missed ANY questions, review the material before you continue.

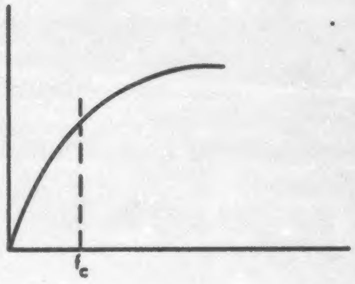
ANSWERS TO C - ADJUNCT GUIDE

1.



2. c

3.



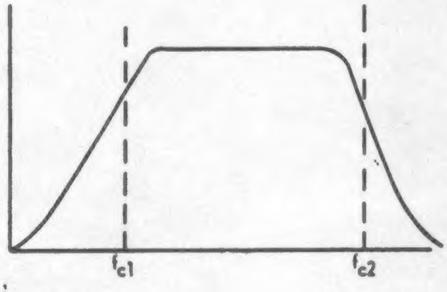
4. b

If you missed ANY questions, review the material before you continue.

ANSWERS TO D - ADJUNCT GUIDE

1. Minimum
2. Maximum

3.



4. a

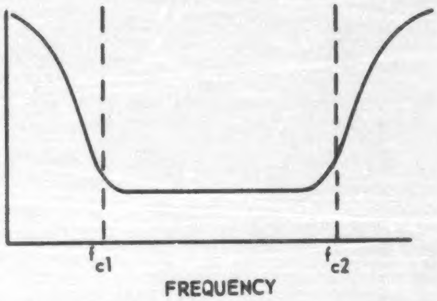
5. Series resonant circuit 25 kHz
   Parallel resonant circuit 25 kHz

6. T and pi types offer equal impedance when looking into the filter from input or output terminals. (Symmetrical filter)

If you missed ANY questions, review the material before you continue.

ANSWERS TO E - ADJUNCT GUIDE

1.



2. b

3. Offers maximum opposition to the resonant frequency.

4. The Q of the circuit.

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK:

1. a

2. c

3. b

4. d

5. b

6. c

7a. F

b. T

c. T

d. F

e. T

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-28

Technical Training

Electronic Principles (Modular Self-Paced)

Module 28

COUPLING

15 July 1975

AIR TRAINING COMMAND

7-7

Designed For ATC Course Use

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Guidance Package 3AQR3X020-X
KEP-GP-28
15 July 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 28

COUPLING

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

Title	Page
Overview	1
List of Resources	1
Adjunct Guide	1
Module Self-Check	2

COUPLING

1. SCOPE: In electronic circuits it is necessary to pass signals from one circuit to another. To pass a signal, the two circuits must be coupled together. Coupling may be direct, inductive, or capacitive. This module will discuss direct coupling, RC coupling, LC coupling, and transformer coupling.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given circuit diagrams and a list of statements, select the statement(s) that explain(s) the operation of

(1) direct coupling.
(2) RC coupling.
(3) LC coupling.
(4) transformer coupling.

b. From a list of statements, select the one(s) that describe(s) the types of coupling that will provide

(1) impedance matching.
(2) desired frequency response.
(3) signal gain.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text

At this point, if you feel that through previous experience or training you are familiar with this subject, you may take the Module Self-Check. If not, select one of the resources and begin study.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

Supersedes KEP-GP-28, 1 July 1974. Previous editions may be used.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers in the back of this guide.

If you experience any difficulty, contact your instructor.

Begin the program.

A. Turn to Student Text Volume III and read paragraphs 11-1 through 11-6. Return to this page and answer the following questions.

1. Coupling is defined as a means by which

______ a. voltage measurements of one circuit are compared to another circuit.

______ b. signals are transferred from one circuit to another.

______ c. signals are attenuated or eliminated from the output circuit.

______ d. reactances are transferred from one circuit to another circuit.

2. Direct coupling is a means of using

______ a. a capacitor to provide a path for signal currents.

______ b. a transformer to provide a path for signal currents.

______ c. an inductor to provide a path for signal currents.

______ d. a resistor or conductor to provide a path for signal currents.

3. When using direct coupling

______ a. the input signal will experience a phase shift in the output of the coupling circuit.

______ b. DC voltages are eliminated in the output of the coupling circuit.

______ c. an exact reproduction of the input signal will be provided to the output of the coupling circuit.

______ d. operation will be limited due to the narrow frequency range of the circuit.

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDE.

B. Turn to Student Text Volume III and read paragraphs 11-7 through 11-15. Return to this page and answer the following questions.

1. The capacitor in an RC coupling circuit blocks

______ a. the AC component and passes the DC component.

______ b. the DC component and passes the AC component.

______ c. both the AC and DC components.

2. Is the following statement true (T) or false (F)?

______ The output signal from an RC coupling circut is taken across the resistor.

3. The AC component to be used in the output of an RC coupling circuit is developed by the

______ a. charging and discharging current of the capacitor through the resistor.

______ b. ratio of X_C to R over the selected frequency range.

______ c. working voltage rating of the capacitor.

_____ d. stray capacitance of the coupling circuit.

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDE.

C. Turn to Student Text Volume III and read paragraphs 11-16 through 11-21. Return to this page and answer the following questions.

1. LC coupling circuits are considered .

_____ a. inductively coupled circuits.

_____ b. resistively coupled circuits.

_____ c. capacitively coupled circuits.

2. With LC coupling, what is the condition of X_C and X_L at the high frequency cutoff point?

_____ a. X_C is high and X_L is low.

_____ b. X_L is high and X_C is low.

_____ c. $X_L = X_C$.

3. Basically RC and LC coupling circuits are

_____ a. high-pass filters.

_____ b. low-pass filters.

_____ c. bandpass filters.

_____ d. band-reject filters.

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDE.

D. Turn to Student Text Volume III and read paragraphs 11-22 through 11-25. Return to this page and answer the following questions.

1. Which of the following is NOT an advantage of transformer coupling?

_____ a. Voltage increase or decrease.

_____ b. Impedance matching.

_____ c. Separation of AC and DC components.

_____ d. Needs less shielding than other types of couplers.

2. Two types of transformers used in transformer coupling are:

_____ a. Radio frequency and audio transformers.

_____ b. Power and radio frequency transformers.

_____ c. Audio and power transformers.

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDE.

MODULE SELF-CHECK

QUESTIONS:

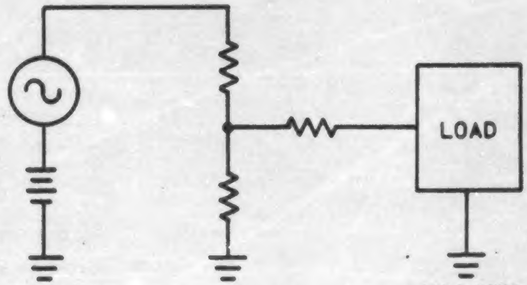
1. Match each diagram with the type of coupling listed below:

a. _____ transformer coupling.

b. _____ LC coupling.

c. _____ RC coupling.

d. _____ direct coupling.



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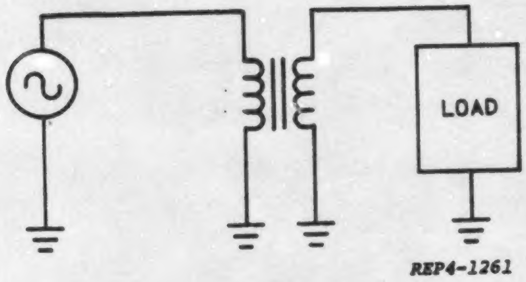
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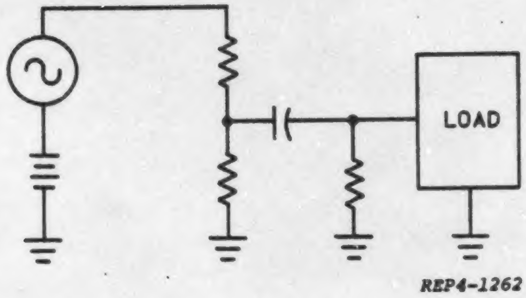
B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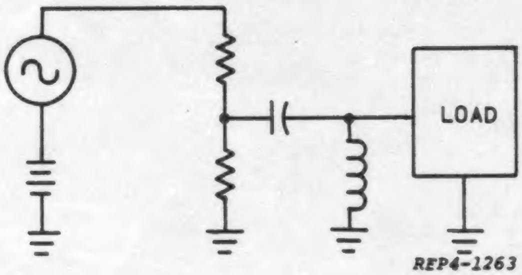
C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D

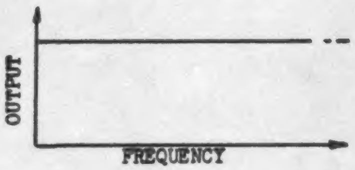
2. Match each response curve with the type of coupling listed below:

a. ______ Transformer Coupling

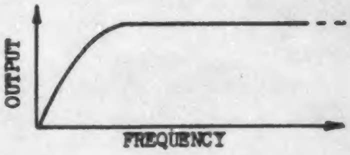
b. ______ LC Coupling

c. ______ RC Coupling

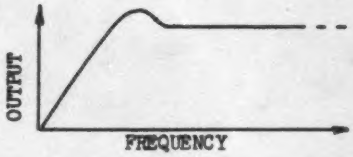
d. ______ Direct Coupling



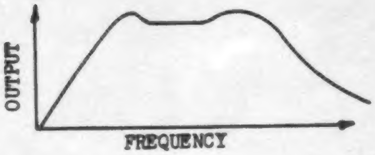
A



B



C



D

3. Match each statement with the type of coupling.

a. ____ Uses a conductor or resistor to connect two circuits together.

b. ____ The ratio of X_C to R determines the low frequency limit.

c. ____ Used to couple a high impedance source to a low impedance load.

d. ____ Provides exact reproduction of input signal.

e. ____ Provides signal gain.

f. ____ Will couple direct current.

g. ____ Has a low frequency series resonance hump.

h. ____ Contains no reactive components.

i. ____ Couples energy by mutual inductance.

j. ____ Steps voltage or current up or down.

k. ____ Produces no phase shift.

l. ____ Has poor frequency response.

m. ____ Has very wide frequency response.

n. ____ Uses a coil as part of the coupling network.

o. ____ Can provide 180° phase shift.

A. TRANSFORMER COUPLING

B. LC COUPLING

C. RC COUPLING

D. DIRECT COUPLING

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDE.

NOTES

ANSWERS TO A - ADJUNCT GUIDE

1. b
2. d
3. c

If you missed ANY questions, review the reference material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. b
2. T
3. a

If you missed ANY questions, review the material before you continue.

ANSWERS TO C - ADJUNCT GUIDE

1. c
2. b
3. a

If you missed ANY questions, review the material before you continue.

ANSWERS TO D - ADJUNCT GUIDE

1. d
2. a

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK

1. a. B
   b. D
   c. C
   d. A

2. a. D
   b. C
   c. B
   d. A

3. a. D
   b. C
   c. A
   d. D
   e. A
   f. D
   g. B
   h. D
   i. A
   j. A
   k. D
   l. A
   m. D
   n. B
   o. A

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTIONS.